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PREFORMED ELASTOMERIC SEALERS IN BRIDGE CONSTRUCTION

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Division of Research&Evaluation Report #29

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PREFORMED ELASTOMERIC SEALERS IN BRIDGE CONSTRUCTION

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by
Bureau of Structures & Materials
Division of Research & Evaluation
New Jersey State Department of Transportation
Trenton, New Jersey

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S U M M A R Y

The basic elements dealt with in this report are:

1. Design Conditions and Functional Elements.
   The purpose of a sealer is to prevent water and other foreign materials from leaking, or otherwise intruding, through the bridge deck to the structural elements below; while still permitting the structure to undergo various movements. Joint sealing is necessary in order to minimize damage to the vital elements of the bridge from corrosion, frost damage, and other detrimental phenomena. This type of sealer, although expensive, is well worth its cost, if it is functionally efficient.
2. Design and Application Criteria.
   Joints and sealers are exposed to the environmental conditions of nature and man-made hazards. The effects of nature amount to prolonged weathering; specifically: heat, sunlight, air, precipitation, and humidity. Included among man-made hazards are those occurring during construction and later due to traffic. All these causes have to be anticipated by the proper qualifications of materials and their applications.

3. Thermal Characteristics of Bridge-End Movements.
   It was observed that the bridge movements at joints are generally caused by thermal influences. The complex problem of determining the magnitude of these thermal movements is discussed, and the need for future study noted. Our analysis focuses on the basic thermal characteristics of a concrete slab exposed on each side.
4. Material and Product Qualifications.
   The subject sealers are so-called two-phase compression sealers. This type of sealer consists of solids and gas, such as elastomers and air. It is preformed in various widths.
   A "functional" compression sealer must constantly exert adequate pressure against the joint sides and permanently plug the joint. It must remain functional while being compressed within the limits of 40% to 80% of its original width. These requirements call for the use of rubber compounds as suitable materials.
   In the material we are evaluating, the base elastomer is polychloroprene, commercially known as "neoprene". A method of design which utilizes the criteria of limits was adopted in modified form, and suggested for use as the best method now

available. Charts #1 and #2 serve as basis for the principal design method and Tables #2 and #3 are guide lines for the design of sealers.

5. Materials Qualification and Identification Specifications.

The use of elastomeric materials in the construction field is recent and unexplored. The structural designers and builders have a relatively poor understanding of elastomers, while most specialists in the field of elastomers seem to be more concerned with material properties than with the functional requirements of application. Primarily for the benefit of the engineer, we discuss the material specifications and propose them on the basis of the best information available. We suggest some minor changes in the properties and the physical requirements with only one purpose in mind: to reduce the service inadequacies of the sealers.

6. Applications of Preformed Elastomeric Joint Sealers.

The subject of this analysis is the actual application of sealers in bridges. The design principles of "simple span" bridges are briefly discussed. Basically, the bridge-deck-ends move parallel with the joints and, at the expansion ends, also in the direction of the span, namely

parallel with the beams. This means that these movements are perpendicular to the joints, except for skewed joints, where they are not at right angles. (Figures 6 and 7). Analysis of th inadequacies in the present practices of design and construction of joints and application of sealers led to recommended revisions in the design concept. Modified solutions shown in Figures #8 and #9a, and two other alternate methods of construction are offered. The first alternate involves sawing the joints; the second is based on the construction of armored joints. A drawback of both alternate methods is a possible increase in the cost of joint construction, offset though, by smaller size seals; and for the first method, it is probable that spalling of the joints' sides will occur due to traffic.

The armored-joints construction method, although the most expensive, is felt to be ultimately worth its expense.

7. Research Data.

The conditions of construction and behavior of sealers in actual field application are of the utmost importance. For these reasons, we observed the construction practices, starting

shortly before sealer installation, during installation, and later periodically, in order to gather functional data on joints and sealers. These data collected, abstracted, and then evaluated, serve as the basis for the analyses and the modifications offered in this report. Here is a brief summation:

1. The sealers were manufactured by shop-vulcanization in sections from 10 to 15 feet long.
2. The lubricant-adhesive was applied on both joint sides. When used in a different manner, trouble occurred.
3. The tools usually provided to apply the lubricant and install the sealers are inadequate.
4. Damages to the concrete at the joints occur during the extraction of forms from the joints and the installation of sealers.
5. The bending of the sealers is difficult and is a cause for inadequacy in performance.
6. Attempts to seal the sealers' open ends have failed.

7. Honey-combing was found to be caused by the excessive reuse of wooden forms and the washing off of the grout by rainwater.
8. No seats for sealers are usually provided in the sidewalks or curbs.
9. Opening of the joints due to the initial setting of concrete was observed.
10. It was established that traffic progressively increases the deterioration of the joints.
11. Sealers placed into joints on a level with the top of the deck or above it are progressively damaged by traffic.
12. Pools of water at curbs are fairly usual.
13. Leakage at the joints has been observed on many bridges.

Tables Nos. 9.1 through 9.8 and 11.1 through 11.7 further substantiate the above observations.

8. Dye Test.

In an attempt to isolate the causes of leakage, a dye test was performed on two bridges. The results indicated three principal causes:

a. Deterioration of joints.

b. Inadequate joint sealing in the gutter area along the curbs.

c. Insufficient compression of sealers.

9. Methods of Observation.

The regular observation schedule was centered around the measurements of bridge-end movements. Out of necessity, the manual methods of measurement were adopted. These measurements enabled us to follow the bridge-deck-end movements parallel and perpendicular to a joint. Graphs Nos. 1 through 12 and Table #4 represent the results of the above manual method.

10. The necessity for instrumentation of bridges as a means of observation was realized as far back as April 1965. The proposed instrumentation goals are: to obtain, through continuous recording for a period of at least one year, the true correlation between the effective temperature of concrete and of air, and between these temperatures and the deck-end movements at joints.

Also, as a by-product, it may be possible to obtain some basis for the further development of formulas for the computation of temperatures between the slab surfaces.

A/ GENERAL

Introduction

At this stage of the well-documented history of bridge-joint sealers, the striking fact is the lack of an adequate solution.

An ideal sealer should be expected to function, under proper design conditions, during the entire life span of a structure. The preformed elastomeric joint sealers were first to fill the void from the design point of view. In the U.S.A. they were applied only a few years ago to highway pavement construction and relatively recently to bridge construction.

In the State of New Jersey, their application in bridge construction is only about two (2) years old.

Their performance in actual construction is therefore little known and their applications are still in the experimental stage. It is the purpose of this research project to gather and evaluate performance data as a contribution to progress in this particular field.

Design Conditions and Functional Elements

To accentuate the importance of the functional purposes of sealers it is necessary to indicate that by sealing off the structural elements below the bridge deck, these are protected from direct damage. Joints that leak and/or

permit intrusion of foreign materials, as is well known, are perpetuating corrosion, frost damage, etc.; these phenomena have very detrimental effects on the vital elements of a bridge structure. The function of a sealer is to avoid them to the fullest possible extent.

A sealer is, as are all other components of a structure, designed to perform under certain definite conditions. Located in a joint between bridge slabs a sealer is exposed to the natural elements in addition to all forms of traffic and the movements of the structure.

These movements are expected to be thermal in character and mainly horizontal in direction, perpendicular and parallel to a joint.

The conditions of construction and the environment of the finished product - a bridge - are quite variable. So much so that, in fact, the behaviour of a structure cannot always be fully predicted at the time of design. To this has been added the risk inherent in the application of controls of the quality of materials as well as of construction; these controls are not always entirely adequate. For these reasons, a certain amount of uncertainty has to be considered as a part of the design of a sealer. Most engineers are familiar with the expression, "a material is patient". Any material applied in a structure, especially in a bridge, has to have a certain amount of "patience" or "safety-factor", that will provide tolerance for unpredictable conditions.

Of course, any kind of structural behavior in excess of what one would term "normally expected", based on experience - such as large settlement of the foundation or creeping of an approach slab - cannot be considered as a "design condition or criterion".

Cost

In making relative cost analyses of different sealers it is necessary to consider the degree to which the purpose is fulfilled and the period of adequate service. The units to be compared are: initial cost of material; installation costs; maintenance costs for sealers and for repairing damage done to other parts of the structure due to sealer deficiencies.

On the basis of such data then, the economically desirable life span of a preformed sealer could be estimated. It is to be regretted that sufficient data of this nature, necessary for making adequate comparisons, are not readily available.

It is, however, not uncommon to evaluate the costs of a structural component in the light of the total cost of a structure. The importance of a joint sealer as a structural component essential to the safety and maintenance of a bridge structure has been outlined above. It justifies the evaluation of the costs of this item in the light of total cost.

In this State, the most commonly used sealer sizes are 2½ and 4 inch, costing $4.50 to $10.00 per foot of length.

About 200 to 300 feet of sealers are used in an average bridge at a cost of about $1,500.00, for a $250,000.00 structure. This represents some 0.5% to 1.0% of the total cost.

It has to be recognized that an efficient sealer in the light of its importance, does justify this expense, even if it rose to 2.0% for higher efficiency. On the other hand, lack of efficiency on the part of a sealer may make even lower costs unjustified since they will be only initial expenses and overall cost will rise rapidly with higher maintenance.

Design and Application Criteria

Among the design conditions we listed, inadequate quality controls and unpredictable behaviour of structures. We have listed them as subject to experience. We will not try to define them since they can only be tolerated as secondary causes and are not the essential subject of this report. Later, however, we will show the effects of at least one of them. At the same time, we wish to make it clear that in design precise provisions cannot be made for excesses in either.

It is worth recalling here that the joints and sealers are exposed to the environmental conditions of nature and man-made hazards.

The effects of nature are best expressed in terms of prolonged weathering, specifically thermal (heat, cold, temperature change), sunlight, air (mainly oxidation and ozone), precipitation, and humidity. Included among man-made hazards are those occurring during construction. These

are mostly due to poor construction practices such as honeycombing, deviation from design dimensions, damages during removal of forms and installation of sealers. Also later hazards due to traffic, such as damaging of joints due to impact and intrusion of foreign material, abrasion, and puncture.

Our observations to date did not indicate any decisive causes for the bridge movements at the joints except for those generally described as thermal. However, further studies, beyond the objectives of this report, will be required to verify certain inconsistencies in some commonly held assumptions.

All these above-mentioned causes have to be anticipated by material qualifications of the sealer and its application. Thus, the problem appears to be two-fold: the material and its application. The material is a base-elastomer, for the time being polychloroprene with additives. The application of the sealer is related to the construction of the joints, the installation of the sealers themselves and, later, the performance of both.

Thermal Characteristics of Bridge-End Movements

We are here attempting only to indicate the thermal characteristics of joint movements and the possible solution of this problem.

It has been recognized (1) that the temperature of a mass, in this case a concrete bridge deck, is influenced by a number of rather complex factors, such as: solar radiation, ambient air temperature, wind velocity, insolation, reradiation, evaporation, conductivity, diffusivity, surface conditions, specific heat and density.

By making assumptions of average values of the secondary parameters and a sinusoidal effective daily temperature cycle, a reasonably simple solution could be obtained.

A reasonably accurate solution would necessitate the gathering and evaluation of a substantial amount of secondary parameter data for each specific location. Since such expanded research is not in the scope of this project, further development of this problem will have to be the object of separate analyses. Thus, assumptions made and data used for this particular discussion are only informative in nature.

In the Highway Research Board Bulletin #168 in the article, "Calculation of Maximum Pavement Temperatures from Weather Reports", by Mr. Edward S. Barber, an equation has been developed for the temperature of a semi-infinite mass in contact with air, which can be expressed as follows:

---

(1) See articles of E. S. Barber and Professor W. Zuk.

$$T=(T_A + R)+\eta_o (0.5T_R + 3R)\, e^{-x\sqrt{\frac{\pi}{t_o a}}} \sin\left(2\pi \frac{t}{t_o} - x\sqrt{\frac{\pi}{t_o a}} - \varepsilon_o\right); (1)$$

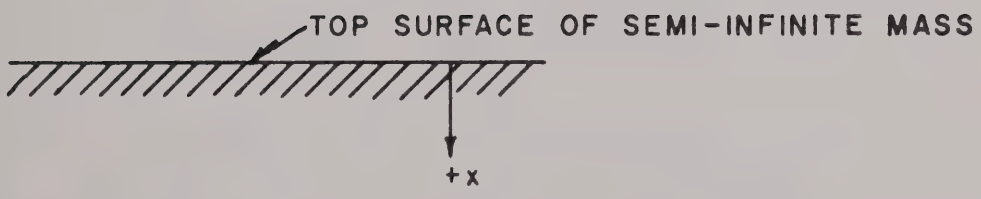
Where: $R = 0.103 \frac{b}{\alpha} L$;

$$\eta_o = \sqrt{\frac{1}{1 + 2\sqrt{\frac{\pi}{H^2 t_o a}} + 2\frac{\pi}{H^2 t_o a}}} ;$$

$$a = \frac{k}{sw} ; \qquad H = \frac{\alpha}{k} ;$$

$$\alpha = 1.3 + 0.62\, v^{0.75} ;$$

$$\varepsilon_o = \arctan \frac{1}{1+\sqrt{\frac{H^2 t_o a}{\pi}}} ;$$



X = distance as measured from the top of mass.

It is obvious that for the top surface of this mass X = 0. Thus, the above formula for the temperature of the <u>top surface</u> can be written in this form:

$$T = (T_A + R) + \eta_o (0.5T_R + 3R) \sin\left(2\pi \frac{t}{t_o} - \varepsilon_o\right); (2)$$

For "T" to become maximum:

$$\sin\left(2\pi\frac{t}{t_o} - \varepsilon_o\right) = 1.0; (x = 0);$$

$$T_{max} = (T_A + R) + \eta_o (0.5T_R + 3R) ; \quad (2a)$$

On the basis of the previously made assumptions, as shown in Table 1, the above equations can be transformed as shown hereafter:

$$T = T_A + 0.0135L + 0.687 (0.5T_R + 0.0405L) ; \quad (2b)$$

Where: L = Solar radiation received on a horizontal surface in Langleys (CAL/CM^2DAY)

α = 4.95; for v = 10.7 mph

a = 0.0334; for k = 1.00 BTU/Ft^2Hour, $^oF/Ft.$;

s = 0.20 $BTU/lb.^oF$ and w = 150 $lbs/Ft.^3$;

η_o = 0.687; for H = 4.95 and t_o = 24 hours

R = 0.0135 L; for b = 0.65 ;

We have been discussing the temperature of a semi-infinite mass, that is a very thick mass exposed on the top only, such as a pavement slab with soil below.

In the case of a slab such as a bridge deck exposed on the top and bottom and a relatively thin mass, the problem becomes different, obviously because of physical limitations exposed to the same influences as previously indicated.

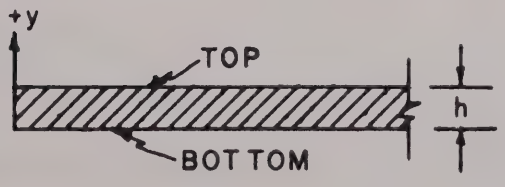
In the Highway Research Record #76, in the article, "Thermal Behavior of Composite Bridges - Insulated and Uninsulated", Professor William Zuk, by superimposing the steady-state heat transfer solutions developed by Carslaw and Jaeger (London, Oxford University Press, 1960) for periodic temperature states on an infinite plate, has evolved the following equation for the time-temperature-depth relation:

$$T=(T_A + \frac{y}{h} R)+ h_o\left[(0.5T_R + 3R)Y \sin(2\pi \frac{t}{t_o} - \Phi + \text{Ln } Y) + (0.5T_R)\ Y^1 \sin\ (2\pi \frac{t}{t_o})\right] ; \quad (3)$$

$$Y=\left[\frac{\cosh 2my - \cos 2my}{\cosh 2mh - \cos 2mh}\right]^{\frac{1}{2}} ;$$

$$Y^1= \left[\frac{\cosh 2m\ (h-y) - \cos 2m\ (h-y)}{\cosh 2mh - \cos 2mh}\right]^{\frac{1}{2}} ;$$

$$m = \left(\frac{\pi}{t_o a}\right)^{\frac{1}{2}} ;$$



y = distance as measured from the bottom of the slab.

According to Professor Zuk "ϕ" is to represent the phase angle difference in the sine-curves of surface temperatures between the bottom and the top of the slab; for the time being there is no analytical expression for its value, since it basically must come from field observations.

Also, at present his opinion is that although Barber's equation #1 seems to predict the magnitude of surface temperatures fairly well, it does not adequately take into account the phase shift between peaks of solar radiation and air temperatures, the phenomenon vital to the analytical determination of "ϕ". However, to date, his tests indicate the time difference to be of the order of 3 hours.

The function of "ϕ" in his formula #3 is in no way intended to relate to the "ϕ" of Carslaw and Jaeger.

In our studies, we also found that there exists a lack of clarity in the problem of the phase shift of solar radiation and air temperature analysis. Apparently this aspect of thermal effects to date, is inadequately resolved.

Professor W. Zuk suggests an empirical approach to this problem. In this way the established values, although probably correct, will be suitable for use only in specific locations.

It seems, though, that an effort should be made to develop theoretically correct analytical expressions, correlated to the actual field observations.

By developing further the equation #3, the temperature of the top surface of the slab is, when y = h:

$$T_{top} = (T_A + R) + \eta_o (0.5T_R + 3R) \sin\left(2\pi \frac{t}{t_o} - \phi\right); \quad (3a)$$

Again, for "T_{top}" to become maximum:

$$\sin\left(2\pi \frac{t}{t_o} - \phi\right) = 1.0; \quad (y = h);$$

$$T_{top\ max.} = (T_A + R) + \eta_o (0.5T_R + 3R); \quad (3b)$$

Formulas (2a) and (3b) are, obviously, identical.
Thus, the temperature of the bottom surface of the slab, when y = o, is:

$$T_{bott} = T_A + \eta_o (0.5T_R) \sin\left(2\pi \frac{t}{t_o}\right); \quad (3c)$$

"T_{bott}" is maximum when:

$$\sin\left(2\pi \frac{t}{t_o}\right) = 1.0; \quad (y = o);$$

$$T_{bott\ max.} = T_A + \eta_o (0.5T_R) \quad (3d)$$

Again utilizing previous assumptions, this equation can be expressed as follows:

$$T_{bott\ max.} = T_A + 0.687 (0.5T_R) = T_A + 0.3435T_R; \quad (3e)$$

And finally the temperature "T" of the slab can be determined from formula #3 for the length of the period "t_o" = 24 hours and various values of time "t", from the beginning of the cycle and the depth of slab "y". Again, assumed average values of secondary parameters are shown in Table 1.

A numerical example of a bridge-deck-slab temperature calculation is presented below to illustrate the preceding synopsis.

A bridge in northern New Jersey was arbitrarily selected.

Date: July 26, 1966

Maximum daily temperature recorded was $90^{o}F$

Minimum daily temperature recorded was $68^{o}F$

Solar radiation received on a horizontal surface is assumed L = 500 Langleys (See Average Solar Radiation charts for month of July in N. J. area). Thickness of the slab is assumed h = 8/12 ft.

From these data:

$T_A = 79^{o}F$

$T_R = 22^{o}F$

Maximum slab top temperature using formula (2b), is:

$T = T_A + 0.0135\ L + 0.687\ (0.5T_R + 0.0405\ L)$;

$T = 79.0 + 6.75 + 0.687\ (11.0 + 20.25)$;

$T = 107.2^{o}F$

Maximum slab bottom temperature using formula (3e), is:

$T = T_A + 0.3435\ T_R$;

$T = 79.0 + 0.3435 \times 22.0$;

$T = 86.55^{o}F$

The numerical analysis of temperature distribution through a slab will have to be deferred to separate studies, as has been already stated. In this report, we attempted only to indicate the basic analysis of thermal characteristics of a concrete slab exposed on each side.

DEFINITIONS	VALUES	AVERAGE VALUES	SOURCE
T_A = average daily air temperature (^oF)		Varies	U.S. Dept. of Comm. Weather Bureau
T_R = daily range in air temperature (^oF)		Varies	U.S. Dept. of Comm. Weather Bureau
R = average contribution to effective air temperature (^oF)	Varies	Varies	
L = solar radiation received on a horizontal surface in Langleys (cal/cm^2day = $3.69BTU/ft^2day$)	Varies	Varies	H. & V., July & Jan. 1949, pp. 62 & 72
k = conductivity of concrete ($BTU/ft^2/hour, {}^oF/ft$)	K=7 to 16/inch	$k=\frac{12.0}{12}=1.0$	Eng. Data Book, p. 5-14 & Guide 1956, p. 178
s = specific heat of concrete ($BTU/lb,{}^oF$)	s=0.19 to 0.27	s=0.20	Eng. Data Book, p. 5-4 & Guide 1956, p. 1175
w = density of conc. (lb/ft^3)		w=150	
b = absorbtivity of surface to solar radiation	b=0.65 to 0.80	b=0.65 (for conc.)	Guide 1956, p. 95
v = wind velocity (mph)	Varies	v=10.7	Guide 1956, p.250-278
a = diffusivity ($ft^2/hour$)	Varies		
α = surface coefficient ($BTU/ft^2/hour,{}^oF$)	Varies		
t_o = length of period (hours)	t_o=24		
t = time from beginning of cycle (hours	Varies		
h = thickness of slab (ft)	Varies		
x = distance as measured from top of mass (ft)	Varies		
y = distance as measured from bottom of slab (ft)	Varies		

TABLE 1
PARAMETER VALUES

In a bridge deck, the slab is often rigidly connected to the supporting beams forming a composite section. Within the scope of this report we will only mention the case of steel beams, where it is not too unreasonable to assume that, due to the high heat conductivity of steel, the temperature of the beams will be the same as that of the ambient air. This was confirmed in "Proceedings of the Symposium on the Stress Measurements for Bridges and Structures", Tokyo, Japan, Japan Society for the Promotion of Science, 1956, in the article, "The Measurement of the Temperature of the Interior of the Reinforced Concrete Slab of the Shigita Bridge and Presumption of the Thermal Stress", by M. Naruoka, I. Hirai, and T. Yamaguti.

Also significant is the configuration of the temperature distribution curve through a slab. Being non-linear it follows an oscillatory wave of decreasing amplitude, as indicated in the mathematical argumentation of heat transfer analysis and confirmed by the tests outlined by Professor W. Zuk, Mr. M. Naruoka, et al. We quote Mr. Zuk: "Generally speaking, in normal bridge structures, a temperature extreme (either hot or cold) at the top of the slab rapidly decays with depth, so that at approximately mid-depth the temperature is virtually the same as at the bottom of the slab". The difference of the top and bottom temperatures can be of the order of $20^{o}F$. Let us remind the reader that the subject study is bridge-end movements reflected in the sealing of joints, not the thermal

stresses. The basic problem therefore is to determine the average effective temperature for a bridge deck.

For clarity we will further elaborate on this subject.

Forgetting the monolithic character of a slab of say $L = 100$ ft., with an average coefficient of expansion $c = 0.000066$ in./ft/^{o}F, the differential movement between top and bottom (if they were free to move separately) would be $\Delta = c\,\Delta t\;L = 0.132$ in. This example is presented of course only to accentuate the problem. This problem is even more pronounced in a composite section, where in the case of steel beams the difference in coefficients of expansion would also have to be considered.

It is obvious that due to the monolithic nature of a slab, all that can be expected is a small amount of rotation of the joint sides. For our purposes, this differential movement can be neglected and only overall average joint side movements should be considered.

In other words, the stabilizing effect of the structural characteristics of a bridge deck will produce, for our purposes, effective average movements.

These average effective movements can be expected to be due to so-called average effective deck temperatures.

Only continuous data, obtained by field observations for a period of at least one year, would give us a lead to such a temperature in the spectrum of the temperature variations discussed in preceding paragraphs.

Consequently, the preceding synthesis is an attempt to make understandable the complexity of the problems and the difficulty encountered in determining the actual effective temperatures which govern the thermal behaviour of the specific bridge elements.

B/ MATERIALS

Material and Product Qualifications

Now that we have explored the influence of thermal effects on bridge-end movements, or, at least, have exposed their complexity, it is proper once more to accentuate the basic requirement of a functional sealer:

It has to be effective in a joint, the sides of which are constantly moving. This is quite apparent from our graphs No. 1 to 12. The subject sealers are so-called two-phase compression sealers (2). This type of sealer which consists of solids and gas, such as elastomers and air, is preformed in various widths; then it is placed in the joint in a pre-compressed state.

The cross-sectional configuration of the ACME Corporation's or the D. S. Brown Company's products could serve as an example. These two products naturally do not exclude any other configuration that would render services required by design and specifications. To clarify the above statements we will only briefly elaborate on the functional limits of precompressed sealers.

The sealer is placed at a certain temperature into a joint whose width "W_j", is equal to about 60% of the preformed width,

(2) Egons Tons, "Materials and Geometry of Joint Seals", published in Adhesives Age, September, 1965.

"W_n" of the sealer. The same sealer must then remain "functional" at a minimum width "$W_{j_{min.}}$" of about 40% of "W_n", to maximum width "$W_{j_{max.}}$" of not more than 80% of "W_n" (see Tables #2 and #3). A "functional" compression sealer must constantly exert adequate pressure against the joint sides so as to permanently plug the joint. For illustration see Figure 1.

FIG. 1a

FIG. 1b

FIG. 1c

For a better understanding of the structural analysis of the subject sealers we suggest a paper published in Highway Research Record No. 80, entitled: "A Structural Approach to Sealing Joints in Concrete", by Donald Dreher.

The above requirements clearly specify rubber compounds as suitable materials. Detailed analysis of rubber coumpounds we leave to specialists in polymers, since even they sometimes seem to disagree among themselves, at least their statements do.

But for an engineer to have a basic understanding of the material he is supposed to utilize, a very general description will be presented here, as outlined for us by a representative of E. I. du Pont de Nemours and Company.

Ingredient	Function
1. Base Elastomer	Determines balance of properties of finished part, subject to limited variation due to compounding.
2. Fillers	Most elastomers require fillers, such as carbon black, to develop their useful strength through reinforcement.
3. Plasticizers	Used in combination with fillers to provide proper hardness. They also can be helpful to low temperature properties.
4. Vulcanizing Agents	Sulfur, metal oxide, or other chemicals that make vulcanization occur under heat.
5. Accelerators	Chemicals which speed up the vulcanization reaction.
6. Antioxidants and/or Antiozonants	Improve resistance of compound to oxygen and ozone.
7. Process Aids (small amounts)	Help manufacturers to process rubber compound in mixing, molding, extruding, and other operations.

In the material we are evaluating in this report, the base elastomer is polychloroprene, commercially known as "neoprene".

Albeit the present knowledge on the contact pressure generated by the compression sealers is insufficient, we consider this functional characteristic to be a key to success or failure of this type of sealer. We therefore especially welcome the paper presented in January 1966 at HRB Committee MC-D3 meeting, entitled: "A Study of Factors Governing Contact Pressure Generation in Neoprene Preformed Compression Seals", by F. Kenneth Hall, Jack H. Ritzi, and Delmont D. Brown.

It is not only a step in the right direction, but also seems to pave the way for establishing badly needed simulated service tests.

In order to develop a criterion along those lines, we adapted and expanded the idea of limits, outlined in Du Pont's "Size Selection of Neoprene Compression Joint Seals" which was summarized in foregoing paragraphs. We term these limits or ratios: efficiency coefficients "X", "Y", "Z".

These criteria are also being used as design conditions in the method proposed by the same Du Pont publication, which is the best positive design approach available at present.

We have adopted this method in a somewhat modified form to suit our purposes. It seems that until more positive and better ways are devised to properly design and size sealers and joints, this one at least is utilizing the basic principle already stated.

Charts #1 and #2 serve as basis for the principal design method, and Tables #2 and #3 are guide lines for the design of sealers.

These tables were developed mainly on the basis of our field observation data collected to date and will be discussed later in connection with our evaluation.

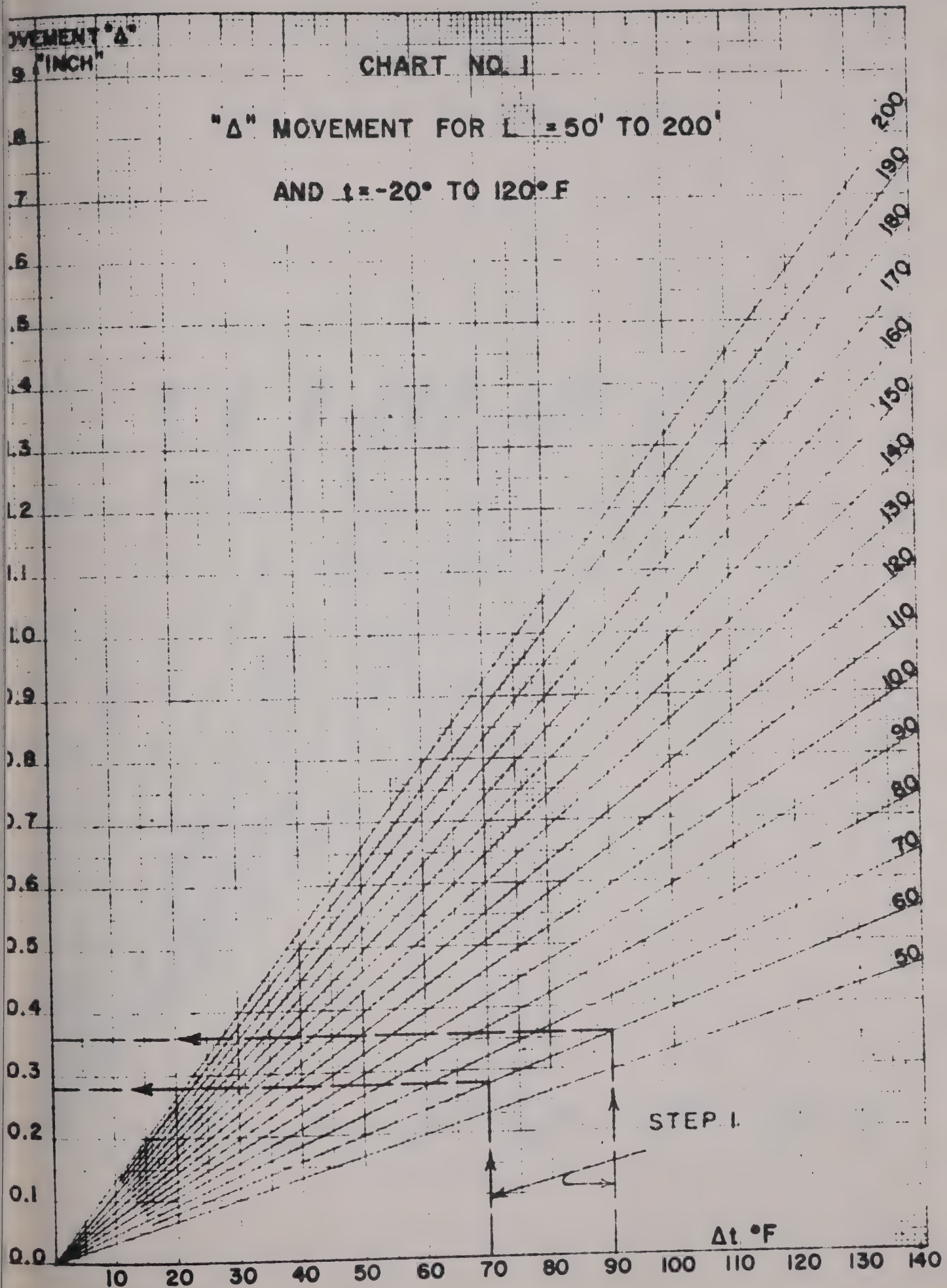
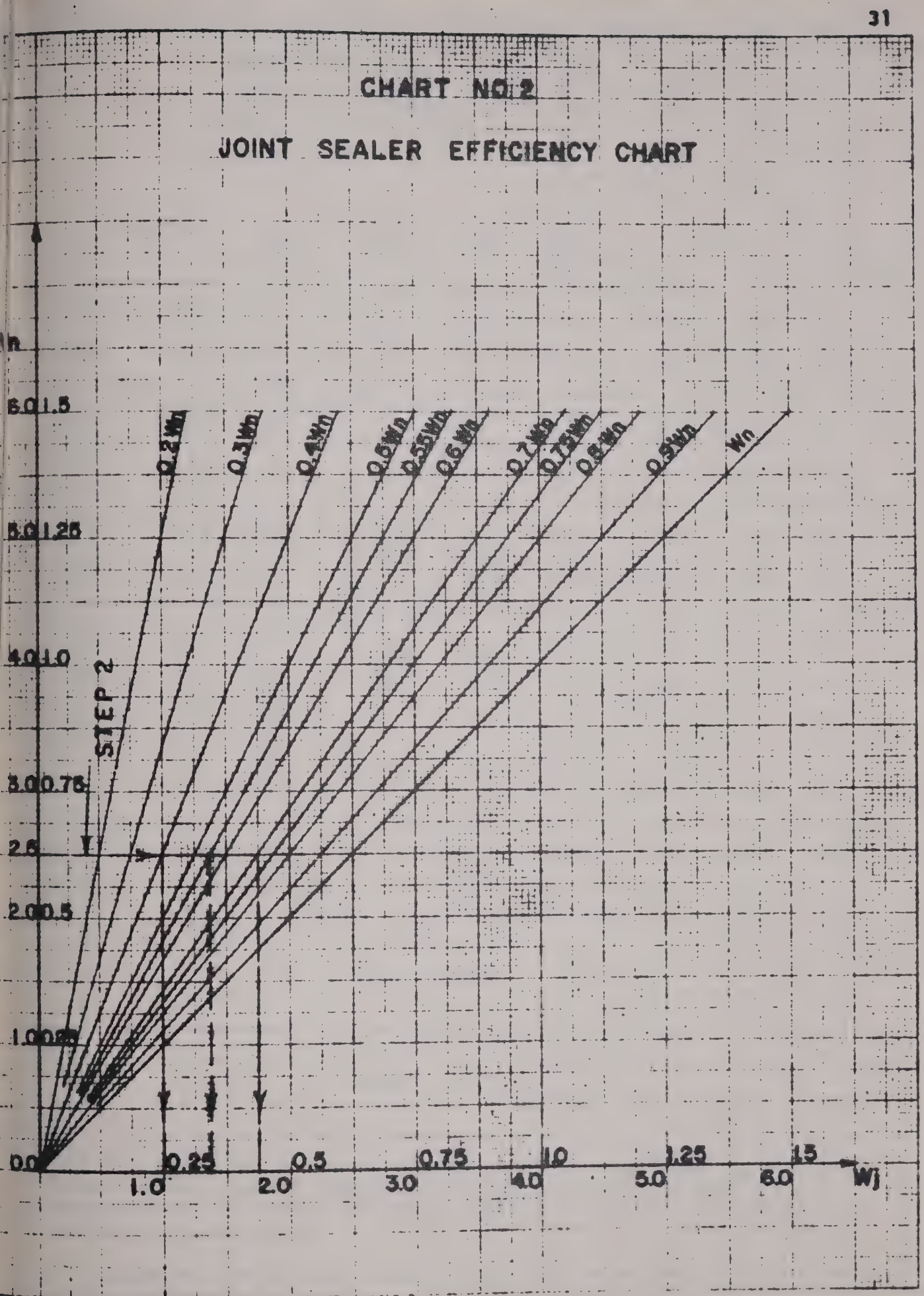

OVEMENT "Δ"
"INCH"
CHART NO. 1
"Δ" MOVEMENT FOR L = 50' TO 200'
AND t = -20° TO 120° F
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
.9
.8
.7
.6
.5
.4
.3
.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
STEP 1.
Δt °F
10
20
30
40
50
60
70
80
90
100
110
120
130
140

CHART NO. 2

JOINT SEALER EFFICIENCY CHART



PROPOSED NEW JERSEY STANDARDS (for present practice) - TABLE #2

Temperature Range: 0^{o} to 100^{o}F
Construction Temperature: 30^{o} to 90^{o}F
Installation Temperature: 30^{o} to 90^{o}F
Degrees of Efficiency: (required)
$Z_{min} = 0.40\ W_n \pm$
$Y_{average} = 0.60\ W_n \pm$
$X_{max} = 0.70\ W_n \pm$

	@100°F		Δ@	@30° to 90°F		Δ@	@ 0°F		
	W_j	Z	Δt=70°	W_j	Y	Δt=90°	$W_{j_{max}}$	X	Limits of Span
"	0.875	0.58	0.0	7/8"	0.58	0.0	0.875	0.58	Up to
	0.86	0.57	0.16			0.21	1.085	0.725	35'
."	0.84	0.48	0.16	1"	0.57	0.21	1.21	0.69	35' to
	0.79	0.45	0.21			0.27	1.27	0.725	45'
	0.915	0.46	0.21	1-1/8"	0.56	0.27	1.395	0.70	45' to
	0.895	0.45	0.23			0.30	1.425	0.715	50'
"	1.145	0.46	0.23	1-3/8"	0.55	0.30	1.675	0.67	50' to
	1.075	0.43	0.30			0.39	1.765	0.71	65'
	1.45	0.48	0.30	1-3/4"	0.58	0.39	2.14	0.71	65' to
	1.38	0.46	0.37			0.475	2.225	0.74	80'
	1.88	0.47	0.37	2¼"	0.56	0.475	2.725	0.68	80' to
	1.74	0.435	0.51			0.65	2.90	0.725	110'
*	2.24	0.45	0.51	2-3/4"	0.55	0.65	3.40	0.68	110' to
	2.15	0.43	0.60			0.77	3.52	0.70	130'
*	2.775	0.46	0.60	3-3/8"	0.56	0.77	4.145	0.69	130' to
	2.615	0.435	0.74			0.95	4.325	0.72	160'

TE: All the above temperatures are those of the concrete. Since these temperatures cannot readily be measured, the daily average temperature of the air with a tolerance of +5 to +10°F would be presently acceptable.

* Because of the lack of experience with these two largest sizes, it is preferable not to use the sealer widths W_n = 5" and 6" until further data are available.

PROPOSED NEW JERSEY STANDARDS (for revised practice) - TABLE #3

Temperature Range: 0^{o} to 100^{o}F
Construction Temperature: 30^{o} to 90^{o}F
Installation Temperature: 30^{o} to 90^{o}F
Degrees of Efficiency: $Z_{min} = 0.40\ W_n \pm$
$Y_{average} = 0.60\ W_n \pm$
$X_{max} = 0.80\ W_n \pm$

W_n	@100°F $W_{j\,min.}$	Z	$\Delta\theta$ $\Delta t=70^{o}$	@30° to 90°F W_j	Y	$\Delta\theta$ $\Delta t=90^{o}$	@ 0°F $W_{j\,max.}$	X	Limits of Span
½"	0.875	0.58	0.0	7/8"	0.58	0.0	0.875	0.58	Up to
	0.621	0.41	0.254			0.327	1.202	0.80	55.0'
¾"	0.746	0.43	0.254	1"	0.57	0.327	1.327	0.75	55.0' to
	0.700	0.40	0.300			0.386	1.386	0.79	65'
2"	0.825	0.41	0.300	1-1/8"	0.56	0.386	1.511	0.76	65.0' to
	0.778	0.39	0.347			0.446	1.571	0.79	75'
2½"	1.153	0.46	0.347	1½"	0.60	0.446	1.946	0.78	75' to
	1.084	0.43	0.416			0.535	2.035	0.81	90'
3"	1.334	0.44	0.416	1-3/4"	0.58	0.535	2.285	0.76	90' to
	1.242	0.41	0.508			0.653	2.403	0.80	110'
4"	1.867	0.47	0.508	2-3/8'"	0.59	0.653	3.028	0.75	110' to
	1.682	0.42	0.693			0.891	3.266	0.81	150'
5"*	2.182	0.44	0.693	2-7/8"	0.57	0.891	3.766	0.75	150' to
	1.951	0.39	0.924			1.188	4.063	0.81	200'
6"*	2.576	0.42	0.924	3½"	0.58	1.188	4.688	0.78	200' to
	2.484	0.41	1.016			1.307	4.807	0.80	220'

NOTE: All the above temperatures are those of the concrete. Since these temperatures cannot readily be measured, the daily average temperature of the air with a tolerance of +5 to +10°F would be presently acceptable.

* Because of the lack of experience with these two largest sizes, it is preferable not to use the sealer widths W_n = 5" and 6" until further data are available.

It is necessary to mention that for now the limits "$X_{max.}$", "$Y_{avg.}$", and "$Z_{min.}$" are obviously emperical values based on experience. These limits or "efficiency coefficients" "X", "Y", and "Z" represent percentages of compression of the initial preformed width "W_n" of the sealer, when it is placed into a joint, as already indicated in this report. These limits or ratios are adapted from the Du Pont publication mentioned above.

To illustrate the application of Charts #1 and #2, and to show hereafter the method used in sizing sealers and joints a solution for a bridge with a span L = 60 ft. follows.

For the State of New Jersey a concrete temperature range of 0^{o} to 100^{o}F is assumed as being realistic. The wide range of sealer installation and construction temperatures of 30^{o}F to 90^{o}F is selected with required limits on efficiency coefficients taken as:

Z_{min} = ±40% at minimum width of joint ($W_{j_{min}}$) and 100^{o}F

$Y_{average}$ = ±60% at installation width of joint (W_{jinst}) and installation temperature from 30^{o}F to 90^{o}F.

X_{max} = ±70% at maximum width of joint ($W_{j_{max}}$) and 0^{o}F

Step 1. For utilizing Chart #1, we consider first that the maximum differences between the extreme temperatures of concrete and of installation are $\Delta t = 70^{o}F$ ($100^{o} - 30^{o}$) and $\Delta t = 90^{o}F$ ($90^{o} - 0^{o}$). On this basis we can read off the chart that $\Delta = 0.28$ in. for expansion and 0.36 in. for contraction.

Step 2. By estimating the sealer size $W_n = 2.5$ in. and utilizing the limits $Z = 0.4\ W_n$ and $X = 0.7\ W_n$ we find from Chart #2 that: $W_{j_{min}} = 1.0$ in., and $W_{j_{max}} = 1.75$ in.

$$\frac{W_{j_{max}} - W_{j_{min}}}{2} = \frac{0.75}{2} = 0.375 \text{ in.} > 0.36 \text{ in. (max. joint movement).}$$

Thus, the joint construction width should be:

$W_{j_{constr.}} = 1\text{-}3/8"$ with $Y_{instal.} = 0.56\ W$

The width of joint ($W_{j_{constr.}}$) is measured at the upper portion of the joint where the sealer is located.

In conjunction with this study of sealer efficiency, graphs Nos. 4 and 8 and table #4 illustrate the practical meaning of coefficients "X", "Y", and "Z". (See pages 147-156 for Table 4).

Later, these graphs and Table #4 will be discussed in detail.

Now that the design functions of these coefficients are clarified and the maximum "X" limitation is identified with the essential functional requirement of positive sealing-pressure, the minimum compression width value (Z in %)

remains to be defined. The polychloroprene sealer has the unique ability to recover its original shape after severe deformation at high and low temperatures. However, if this sealer is compressed beyond its minimum recommended width ($W_{j_{min}}$ at Z_{min}) permanent damage to the seal will eventually occur (cracks, permanent shape deformation, etc.); the sealer might be even extruded from the joint.

To comprehend the mechanics of this type of failure, one must recognize the following design phenomenon of a two-phase compression sealer.

At a "minimum compressed width" the air space within a seal is practically eliminated, while the solids (elastomers) should not be compressed.

Infringement upon this limitation would result in eventual failure, as noted above.

As a consequence of the minimum-width criterion, the shape and the wall thicknesses of the sealers have to be specified. Testing procedures have therefore to be set up, for controlling and enforcing these specifications. In doing this, care must be taken not to endanger the positive sealing pressure when the joint reaches its maximum width.

Tables #5 and #6 and Figures #2 to #5 exemplify the sealer's dimensional problem. Table #7 shows the results of sealer tests in some of our bridges presently under observation. The Tables #5 and #6 are based on the required

sealer's design dimensions, not those actually measured. The idea is to indicate how restrictive the dimensional tolerances must be to actually manufacture satisfactory products.

From these tables, it is apparent that not only the thicknesses, but also the configurations are responsible for the sealer's minimum width and that Product "K" needs to be improved to satisfy the Z_{min} = 40% requirement. It appears that this can be done without necessarily changing its configuration and thus endangering other requirements of sealer design. Incidentally, the same trend appears in the requirements specified by the State of Pennsylvania.

In table #7 the cracking of test samples of sealers during recovery tests is also an indication of the necessity to keep the actual minimum width at the required level, as discussed in previous paragraphs. It seems that the solids in these sealers were compressed, causing cracking and thus possible future failure of sealers.

It is to be noted that these sealers were installed in wider joints under lower percentage of compression than required by design (see our summation in Table No. 4). Thus, their minimum width will probably not be critical, but their criterion of positive contact pressure is. There is an indication that this is the case, since the joints in which they are placed are already leaking.

FIGURE NO. 2

(Manufacturers A & B)
Samples of Sealer Product "K"

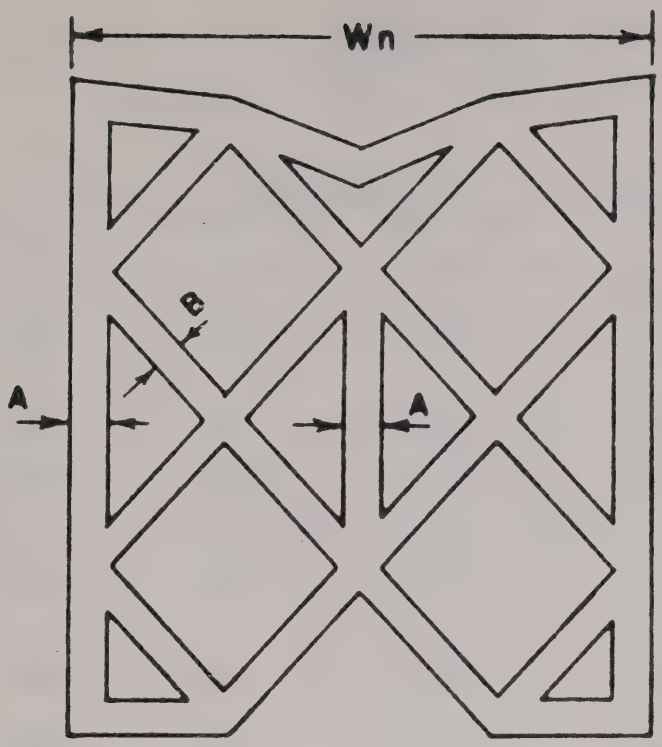


FIG. 3
Sealer Configuration
(Product "K")

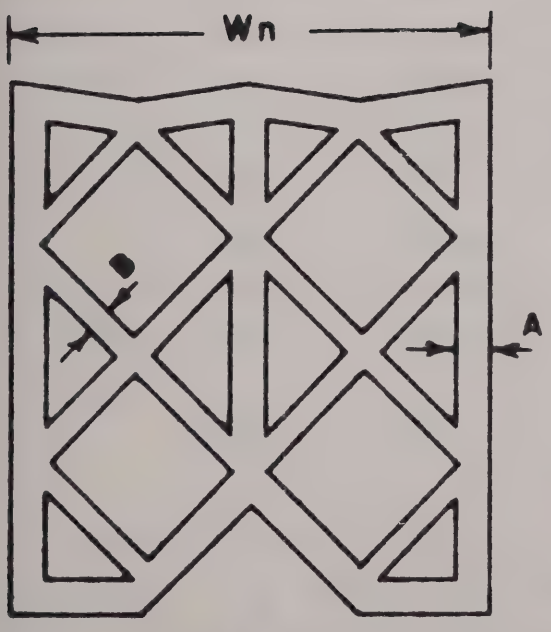


FIG. 4
Sealer Configuration
(Product "L")

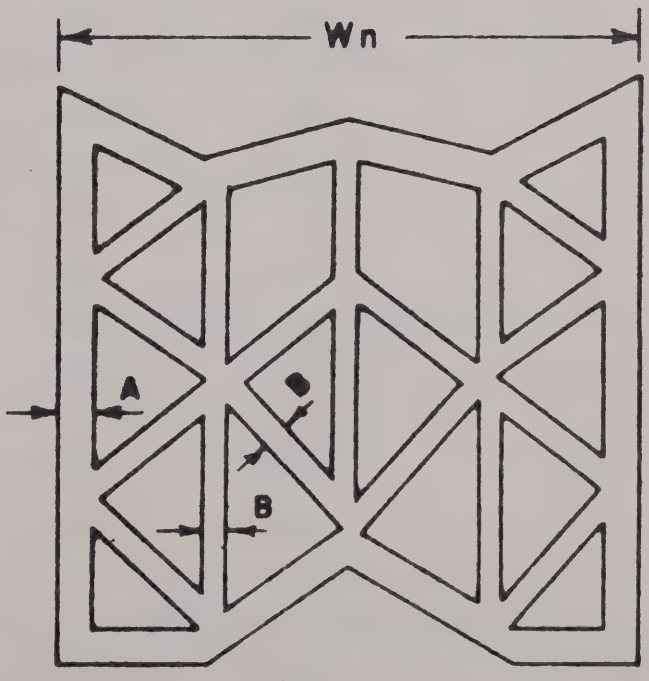


FIG. 5
Sealer Configuration
(Product "L")

FIG. 3,4&5

TABLE #5
(Product "K")**
Samples of Sealers' Minimum Width

Sealer Width "W_n"		Thickness of Shell "A"	Thickness of Web "B"	Min. Width 4(A + B)	"Z" in % $\frac{4(A + B)}{*W_n}$ x 100
1-3/4"	+ 3/16" -0.0" max.	5/32	7/64	1.07	55
	nom.	1/8	3/32	0.88	50
	min.	7/64	1/16	0.69	40
2"	+ 3/16" - 0.0" max.	5/32	1/8	1.12	51
	nom.	1/8	3/32	0.88	44
	min.	7/64	5/64	0.75	38
2½"	+ 1/4" - 0.0" max.	15/64	1/8	1.44	52
	nom.	3/16	3/32	1.125	45
	min.	11/64	5/64	1.00	40
3"	+ 1/4" - 0.0" max.	15/64	11/64	1.63	50
	nom.	3/16	1/8	1.25	42
	min.	11/64	7/64	1.12	37
4"	+ 5/16" - 0.0" max.	19/64	15/64	2.13	50
	nom.	1/4	3/16	1.75	44
	min.	7/32	11/64	1.56	39

* W_n maximum or W_n nominal was used to compute Z% depending on whether maximum, nominal, or minimum thickness of the shell and webs was used.

$$Z\% = \frac{4(A + B)\ (max)}{W_{n_{max.}}} \quad \text{or} \quad \frac{4\ (A + B)\ (nom.\ or\ min.)}{W_{n_{nom.}}}$$

** See Figure #3

TABLE #6
(Product "L")**
Samples of Sealers' Minimum Width

Sealer Width "W_n"		Thickness of Shell "A"	Thickness of Web "B"	Min. Width (3A + 4B)	"Z" in % $\frac{(3A + 4B)}{*W_n} \times 100$
1-5/8"	+ 0.156" max.	5/64 + 0.016	5/64 + 0.016	0.66	37
	- 0.00" nom.	5/64	5/64	0.55	34
2"	+ 0.156" max.	7/64 + 0.032	7/64 + 0.032	0.99	46
	- 0.00" nom.	7/64	7/64	0.77	39
2½"	+ 0.218" max.	3/16 + 0.032	1/8 + 0.032	1.29	47
	- 0.00" nom.	3/16	1/8	1.06	43
2-3/4"	+ 0.218" max.	3/16 + 0.047	1/8 + 0.032	1.33	45
	- 0.00" nom.	3/16	1/8	1.06	39

				Min. Width (2A + 7B)	"Z" in % $\frac{(2A + 7B)}{*W_n} \times 100$
3"	+ 0.250" max.	3/16 + 0.047	1/8 + 0.032	1.33	41
	- 0.00" nom.	3/16	1/8	1.06	35
	min.	3/16 - 0.032	1/8 - 0.016	0.95	32
4"	+ 0.313" max.	1/4 + 0.047	1/8 + 0.032	1.52	35
	- 0.00" nom.	1/4	1/8	1.25	31
	min.	1/4 - 0.032	1/8 - 0.016	1.09	27

*W_n maximum and W_n nominal was used to compute Z% depending on whether maximum, nominal or minimum thickness of the shell and webs was used.

$Z\% = \frac{(3A + 4B)\ (max.)}{W_{n_{max.}}}$ and $\frac{(3A + 4B)\ (nom.)}{W_{n_{nom.}}}$ ** See Fig. 4 & 5

or $\frac{(2A + 7B)\ (max)}{W_{n_{max.}}}$ $\frac{(2A + 7B)\ (nom.\ or\ min.)}{W_{n_{nom.}}}$

Test Samples
Date of Tests: March 1966

TESTS	SAMPLES TESTED								PHYSICAL REQUIREMENTS
	4"	2½"	2½"	2½"	1-3/4"	2½"	2½"	2½"	
Tensile Strength psi	1820	2620	2400	2300	2800	2800	2800	2600	2000
Elongation %	290	370	350	270	290	280	280	330	250
Hardness, Points	57	56	54	59	60	63	60	55	55 ± 5
Ozone Resistance 3ppm 70 hrs. @ 104°F 20% Strain	OK	OK	OK	OK	OK	OK	OK	OK	No Cracks
Oil Swell ASTM #3 oil, 22 hrs. @ 212°F, Weigh change %	64	34	34	30	29	27	29	32	+45
Recovery Tests (under 50% deflection) % 22 hrs/212°F	76	92	88	84	86	92	92	90	*85 (Du Pont)
70 hrs/212°F	54	84	76	66	76	82	82	76	*74 (D.S. Brown
72 hrs/+14°F	32	76	80	14	70	62	66	64	*75 (Du Pont)
22 hrs/-20°F	40	68	74	12	60	52	56	52	*65 (Du Pont)
@ 50% deflection				Cracked		Cracked	Cracked		No Cracking or Splitting
Manufacturer & Product	A(K)	B(K)	B(K)	A(K)	B(K)	B(K)	B(K)	A(K)	
Date Installed	8/64	7/65	6/65	7/65	10/65	10/65	10/65	11/65	
Bridge No.	#5	#7	#10b	#9b	#15a & c	#15a & c	#15a & c	#17a to f	

* Calculated recoveries as expressed above are percentages of the original deflections as follows:

$$\% \text{ Recovery} = \frac{\text{Revovery width-compressed width}}{\text{50\% original width}}$$

Material Qualification and Identification Specifications

As already stated elsewhere, the use of elastomeric materials in the construction field is recent and unexplored. The structural designers and builders have a relatively poor understanding of elastomers compared to the more common construction materials. On the other hand, most specialists in the field of elastomers seem to be more concerned with material properties than with the functional requirements of applications. Thus, it should be made quite clear that at the present time nobody seems really to know which properties best express the actual performance of the material when it is used as a preformed elastomeric joint sealer.

As a result, presently available specifications have very little basis in fact since on the one hand, there is hardly any correlation between them and the actual sealer application; on the other hand, not enough testing was done on actual seals.

We already made an effort to improve the understanding of the material by the engineer and of the functional criteria by all concerned. Now, mainly for the benefit of the engineer, we will discuss the material specifications; we shall present them on the basis of the best information available, as we see it.

For best understanding, we will start with Table #8, "Material Qualification and Identification Requirements", covering the sampling, test procedures, certification and

acceptance requirements. These are, in effect, the material specifications.

For simplicity of identification, we grouped and numbered the tests.

The test specifications themselves follow the table.

TABLE #8

TESTS FOR QUALIFICATION AND IDENTIFICATION REQUIREMENTS

NO.	PROPERTIES DETERMINED ON ACTUAL SEALS	TEST PROCEDURE	PHYSICAL REQUIREMENTS
up I			
1	Tensile Strength, psi, min.	D412	2000
2	Elongation at Break, % min.	D412	250
3	*Hardness, Type A. Durometer	D-2240	55±5
4	Permanent set at Break, % max.	D412	10
up II			
5	Oven or heat aging 70 hrs./212°F a. Tensile strength, change, max. % b. Elongation, change, max. % c. Hardness, Type A, points change, max. %	D573	 +10 to -20 -20 0 to +10
6	Ozone resistance (test on oven aged material) 20% strain, 300 pphm in air, 70 hrs./104°F(40°C) (Wipe with solvent to remove surface contamination)	D1149	
7	Oil Swell, ASTM Oil #3, 70 hrs./212°F Weight Change, max. %	D471	+45
up III			
8	**High Temperature Recovery 70 hrs./212°F under 60% deflection	D395 Method "B" (Internal) surfaces not talced)	85% min. (no cracking or splitting)
9	**Low Temperature Recovery, 72 hrs./+14°F under 50% deflection	D395 Method "B" (talcing desirable)	88% min. (no cracking or splitting)
10	**Low Temperature Recovery, 22 hrs./-20°F under 50% deflection	same	83% min. (no cracking or splitting)

he hardness test shall be made with the durometer in a durometer stand as ecommended in D-2240.

Cracking or splitting of specimen during recovery shall mean that specimen has failed the test.

Tentative Specification

Sampling: All test sections used in the tests shall be cut and buffed from the actual extruded compression joint seal. A minimum of five linear feet shall constitute one sample for testing purposes.

Test Procedure: In all tests, the material to be tested shall be furnished from standard production. Specimens for the high and low temperature tests shall consist of five-inch lengths taken at random from each new shipment of the preformed sealers. In the high temperature test, only the outside surfaces may be dusted off to prevent them from sticking to the steel compression plates. For the cold tests, talcing of either surface is desirable. Deflect the sample between parallel plates to 50% or 60% (as table indicates) of the original top width. Each width measurement shall be taken in the center of a five inch length, using a dial gauge graduated in thousandths of an inch. The gauge shall have a 1/4 inch diameter foot and shall be mounted on a platform. For width measurements, the top longitudinal edge of the specimen shall be placed at the center of the foot of the gauge. The foot's position shall be carefully marked on the specimen before the first gauge reading is made.

Prior to compression, the specimen shall be placed in such a horizontal position that the plane, through both edges of the top surface of the joint sealer, is perpendicular to the compression plates. As the specimen is being compressed the top surface

of the joint sealer shall fold inward toward the center of the specimen. The compressed width shall be measured on the centers of all four (4) sides of the clamp assembly with carefully calibrated internal calipers.

High Temperature Tests: Expose the clamp assembly with the compressed specimen for 70 hours in an oven maintained at 212°F±2°F. Do not pre-heat the clamp assembly. When the aging period in the oven is completed, remove the clamp assembly and immediately unclamp the test specimen. Cool the test specimen at room temperature (73°F±4°F) on a wooden surface for one hour before measuring the heat-aged recovery-width; this measurement is to be made at the same location as the original width. Calculate the recovery.

Low Temperature Tests: Expose the clamp assembly with the compressed sample in a frost-free refrigerated box for the time and at the temperature specified (see table 8). To achieve the frost-free condition, a sufficient amount of a desiccant such as calcium chloride shall be placed into the box. When the cold aging period is completed, unclamp the test specimen at the test temperature; allow it to recover for four hours, in a free state at the test temperature. At this point, measure the recovery width at the test temperature. The measurements shall be made at the location at which the original width was determined. Calculate the recovery.

Calculations: Calculate the recovery, expressed as a percentage of the original width, as follows:

$$\% \text{ Recovery} = \frac{\text{Recovered width}}{\text{Original width}} \times 100$$

Certification and Acceptance: Each lot of the joint seal shall be identified with the manufacturer's name or trade mark and shall be accompanied by the manufacturer's affidavit attesting his conformance with the test requirements as well as a copy of the manufacturer's test report.

Each certification so furnished shall be signed by an authorized agent of the manufacturer.

The following DISCUSSION OF THE TESTS was developed with the assistance of the organization of E. I. du Pont de Nemours and Company.

By now the exclusion of molded test specimens from the specifications appears to be accepted, on the grounds of not being representative and even misleading.

Group I Tests #1 to #4 (tensile strength, elongation, hardness and permanent set at break)

These tests are widely used to characterize rubber products. They give very little useful information themselves, since they only describe "original" properties measured right after vulcanization. But they do tend to establish the broad quality classification of the product.

The rubber industry uses the word "quality" in a specific context. When applied to a particular compound, "quality" refers to the degree to which the maximum properties available from the polymer have been developed. In most elastomers, polychloroprene included, there must be other ingredients in the compound, as already indicated, to develop optimal properties. Therefore, even the highest "quality" compound will not contain more than 60-65% elastomer by weight. Since the elastomer is the most expensive major ingredient in a rubber compound, the higher the percentage of elastomer, the more expensive the compound will be.

Tensile strength and elongation, in a given hardness range, give an immediate indication of quality level, because these properties reflect the degree to which the compound has been diluted. Permanent set indicates whether or not the compound has reached its optimum state of vulcanization and is reflected in stress relaxation or creep. The hardness test gives only an approximate value; it therefore is not an adequate measure of load carrying capacity (stiffness). As stated before, however, the product must be further defined by other tests in order to determine its usefulness in a given service.

Group II Tests #5 to #7 (oven aging, ozone resistance, and oil swell)

These tests serve a two-fold purpose:

1. To measure the effects of various environments on the rubber product and

2. To identify the elastomer used.

Note, please, that the degree to which these tests measure the resistance to aging in different environments depends on how well the test is related to actual exposure. Precise correlation is difficult, if not impossible, to obtain without intensive study over long periods of time.

Oven aging is a rough indication of how well a rubber product will resist age deterioration, which includes oxidation effects, as well as other deteriorating factors such as heat.

The ozone test, on the other hand, measures resistance to a specific deteriorating influence. Many types of rubber are susceptible to severe attack from ozone. Since ozone is present in the atmosphere, resistance to ozone attack is necessary for a material to withstand prolonged weathering.

While oxygen affects the entire unit of the material, ozone attacks the surface, causing cracks which open under loading, exposing it to further ozone damage and possibly rupture under stress.

Volume increase in oil is not a true indication of the resistance of an elastomer to deterioration. If one were testing for deterioration, then one should determine retention of physical properties after oil aging. Although polychloroprene is a medium-swell elastomer, it retains physical properties better than the so-called low-swell elastomer. In this specification, the oil test (combined with the ozone requirement) served mainly to help assure that the elastomer is polychloroprene.

The Group I and II properties must be viewed as a composite. No elastomer compound can be designed to have the maximum desirable levels of all properties. What is done to improve one property may hurt another. Therefore, each compound is a compromise. The compound must have a balance of good levels of the properties most necessary to good service.

Group III, Tests #8 to #10 (recovery tests)

While one could not quite think of the recovery tests as simulated service tests, they bear more resemblance to service conditions than the others. The high temperature recovery test (#8) is an indication of how completely the seal is vulcanized. Poorly vulcanized seals would tend to take too high a set after being compressed in a highway joint. At this time, there are not sufficient field data to allow anyone to attempt to correlate a given recovery value with some specific useful life in a joint.

The low temperature recovery tests have a different purpose. A seal will not pass these two tests (#9 & #10) unless it has been compounded to resist both crystallization and thermal stiffening. The recovery requirement at $+14^{o}F$ is designed to insure that a crystallization-resistant neoprene polymer is used. The $-20^{o}F$ test will assure specifically that the compound has a good level of low temperature flexibility and that the brittleness characteristics will be controlled.

The plasticizers improve flexibility and depress the brittle point of materials at low temperatures. The -20°F temperature appears to be adequate for the area of the State of New Jersey.

The function of the material specification is to set practical limits on the important properties from a production standpoint, as well as to insure the procurement of serviceable material. Irrelevant tests should be avoided.

There are also other basic rubber material tests such as the tear compression set, and the one on low temperature stiffening. These tests are omitted from our proposed specifications as outlined above, because they are irrelevant and could even be misleading for sealer service purposes.

We are using the recovery tests to take the place of the low temperature stiffening and compression set tests. The tear test, although valid, cannot be performed properly by presently available methods.

Both the recovery and compression set tests indicate the state of cure. Curing is executed on an already extruded product. A balance must be maintained between compression set and tear: an undercured material will cause excessive set, an overcured one will result in cracking. Obviously, neither is permissible.

The compression set on the preformed sealer, designed as a structural unit, is best represented by recovery tests, since the compression set test is performed on the solid sample of material, while the recovery tests are conducted on a sample of a sealer unit.

Furthermore, these sealers are specifically designed always to act as a structural unit within certain limits; compression beyond these limits might result in failure. Therefore, a compression-set test on solid material is not entirely representative and may even be misleading.

Both tear-compression set tests are generally good when run exactly as prescribed by ASTM. When performed on samples obtained from finished seals they can be extremely clouded by error.

As indicated, the balance between the above tests is essential regarding the state of cure. This is why it appears desirable to include in the future the tear test in the Q-I specifications, as soon as satisfactory methods of testing are developed.

In the foregoing we have suggested some changes in the physical properties and requirements to be specified and tested. These suggestions can now be reviewed.

The round-robin tests performed for the ASTM Committee D-4, Subcommittee 3e, have indicated the increase as well as the loss of tensile strength after oven aging. Since the increase of tensile strength in this test indicates somewhat undercured material it seems advisable to limit both.

In the high temperature recovery test, we increased the percentage of deflection to 60%. This is being done to facilitate the Z_{min} = 40% design, installation, and material

requirements. In the same test, the 70 hrs./212°F requirement seems to eliminate more efficiently the inadequate material.

These changes, with some other minor ones, have only one purpose in mind: to reduce the sealer service inadequacies observed in the field. We are aware of the fact that by tightening the material requirements we have to expect criticism, especially from the sealer manufacturers.

The fact we have to face is that to date, in New Jersey, sealers in bridges under observation have failed in various degrees - joints are leaking.

Some will argue the degree of failure, although it is beside the point in our discussion. At the present time the observed inefficacy cannot always be attributed directly to an inadequacy of a sealer material. But one thing has been established: almost all sealers were installed at higher than 60% (Y) compression and many relaxed in winter months to more than 80% (X).

For the present, considering the methods of joint construction used in New Jersey, the sealers should be compressed during installation to about Y = 55% and should never relax to more than X = 70% (see Table #2).

Further, as indicated in the cost analysis, this type of material is expensive; therefore, inefficient utilization of the sealers may not justify their costs. This can very easily happen if efforts are not made to meet the requirements suggested in this report. We believe they can be met (see

Table #6) provided all concerned endeavor to improve quality. It appears to us that this type of seal can solve the problem of joints in a large percentage of bridges.

As concerns the "lubricant-adhesive" material as presently used to facilitate the application of these seals, it is useful as a lubricant. But during prolonged periods of high temperatures (above 90°F) it has the tendency to set rather quickly while being applied. For all practical purposes, it is admittedly an adhesive "by name only", as was observed in the field.

All told, expanded research on better bridge joints, as already outlined, is a growing need. This is why we are already proceding with the implementation of an improved program along these essential lines:

1. Thorough testing of all sealers to be utilized on actual construction in accordance with our specifications.

2. The same kind of testing of all sealers removed from joints for reasons of failure or otherwise.

3. Testing for the purpose of research.

As indicated before, the direction of this research will be toward further development of the idea of positive retention of contact pressure in conjunction with minimum compressed width and sealer recovery.

The ultimate goal of all this measuring, recording and correlating will be to evolve some kind of simulated service tests related to actual field application and to the specific period of useful life in a joint.

C/ APPLICATIONS

Applications of Preformed Elastomeric Joint Sealers

Up to now we have discussed the theory of bridge joints and their sealing principles as well as the material used in this type of sealers.

The second portion of the joint sealing problem, namely the actual application of sealers in bridges, will be the subject of our next analysis.

The best program for this discussion will be to follow the practice of DESIGN AND CONSTRUCTION.

The vast majority of bridges in New Jersey are designed as "simple span" bridges regardless of whether they are of single or multi-span type. The span of these bridges extends mostly to a maximum of 100-150 ft. The "simple span" criterion requires one end of the span to be "the fixed end", the other to be "the expansion end". At each end in the approximate middle of the width of the bridge, so called "alignment bearings" are located (see Fig. 6 & 7). In this paper there is no need to explain the details of bearing construction. But it is important to keep in mind that the design assumptions for bridge-deck-end movements are as follows:

At the fixed end the assumed movements are between A.B. and the outsides of the bridge and are parallel with the joints.

In practice it was observed that "fixed" ends also move an average of about 1/8", but sometimes as much as 1/4", in the direction of the span.

At the expansion end the movements are designed to be parallel with the joints in the same manner as at the fixed end, and also in the direction of the span.

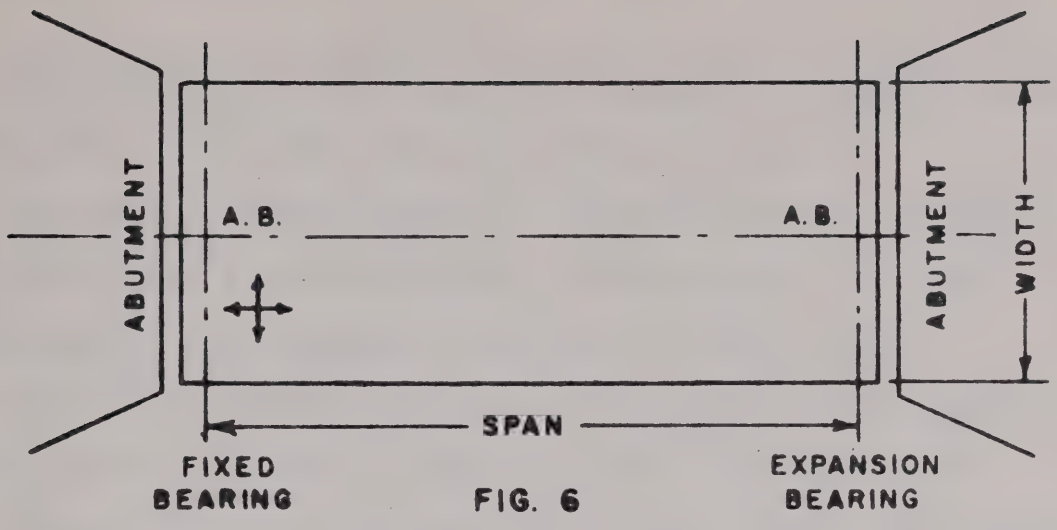


FIG. 6

Schematic Sketch of Single Span Bridge

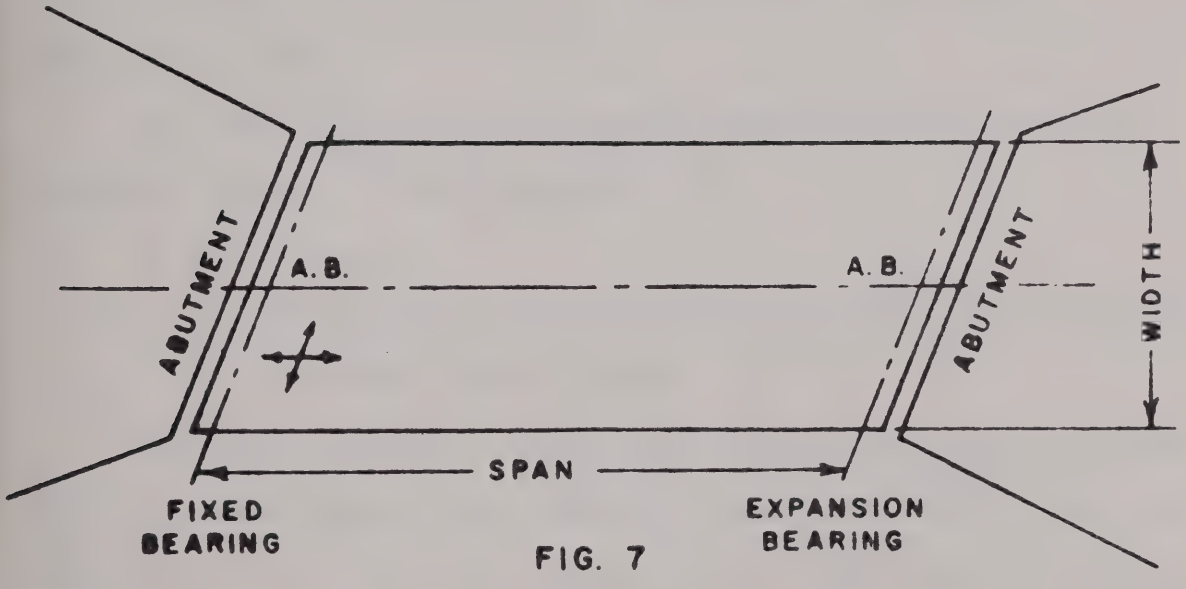


FIG. 7

Schematic Sketch of Single Span Skewed Bridge

Legend

A.B. = Alignment Bearing

Direction of bridge deck—end movements

FIG. 6&7

For the joints, the deck-end movements in the direction of the span translate in the following fashion:

Ordinarily, these movements are parallel with the beams and, therefore, are perpendicular to the joints, but for skewed joints these movements are not at right angles.

This last condition has adverse effects on the sealers in the joints of skewed bridges, as will be shown later.

Figures 6 and 7 are meant to visually clarify the above discussion.

As explained before, the deck-end movements are expected to be thermal in character and, therefore, are usually designed as such.

The practical formula normally used to determine the expected amount of end movements is:

$$\Delta v = c \quad \Delta t \quad L$$

Δv = the amount of bridge-deck-end movements in inches

c = 0.0000055 inch/^{o}F/inch

This is an average coefficient of expansion for concrete. Its value may actually be higher or lower, depending upon the concrete mix and the field conditions of the particular construction site.

Δt = the effective change of temperature of the material in ^{o}F. See the discussion of thermal effects in the general chapter (A) of this report.

L = the effective length of the structural element, a bridge deck, in inches.

For practical reasons, the assumptions of average values must be made, naturally, within safe and sound limits. Thus, the "c" value is assumed as indicated above, "L" is always a variable. "Δ t" is calculated, as indicated before, regretfully in an oversimplified way for this type of sealer.

However, this is how the width of the open deck joint is established with some safety factors included, for reasons mentioned in earlier sections. One must remember, though, that joints were used in bridges long before the subject sealers were offered. The practices useful then are sometimes still utilized without realizing their impropriety. The use of preformed bituminized joint fillers and water stops in joints at abutments are examples of this practice.

The water stop may do some good if the sealer is not quite functional. The fillers, however, are harmful since in the actual construction they are utilized to form joints which are, too often, rather inadequate and fillers are not elastic enough.

It must of course be remembered that to take full advantage of preformed sealers the design, in all details including the construction of joints, should be purposeful, accurate, and of good quality.

Kinks and bends in the horizontal alignment of joints, for example, left over from old practices must be eliminated. This requirement is more important for elastomeric joint sealers than it was previously under the old methods.

The sealer must be installed in the transverse joints as straight as possible and in a continuous length across the full width of a bridge, regardless of whether they are at piers or abutments. Longitudinal joints in bridges should be avoided, since to seal them efficiently is impossible unless methods are devised to weld-join the sealers in the field. To our knowledge such "magic glues" are not yet available.

The straight and continuous joint requirement refers mainly to skewed bridges and, even if the reasons for established practices are fully comprehended, the need for changes is often imperative in order to facilitate the proper functioning of this type of sealer. For example, what is the use of sealing the joints throughout the roadway only to find water freely leaking through the same joints at curbs, sidewalks, and parapets, places where water and snow are most often accumulated. Our field observations fully substantiate that such leaking does frequently occur.

Presently in many states, as in New Jersey, the installation details call for the sealer in the roadway to be bent up into the sidewalk a few inches behind the curb line. Further the sidewalk sealer starts at the bottom of the curb and is immediately bent almost 90^{o} in order to continue in the joint near the top of the sidewalk, where it is terminated in a foot or two at the inside face of the parapet. All these and other details are often most unfortunately designed, as in

the case of sidewalk bulkheads poured integrally with the roadway; joints of skewed bridges, horizontally sharply bent at the curbs and/or parapets; seats for the sealer omitted at the curbs.

The design of these details is sometimes too complicated and disregards hydraulic principles.

In the first place, good solutions are generally simple, and secondly, it is very difficult to seal a moving joint where moisture is allowed to remain accumulated for a period of time. Whatever the reasons, these are the sore spots on every bridge, as our observations clearly indicate.

The troubles begin with the execution of joint construction, they continue through the installation of the sealers, and result too often in the failure of the sealing system. All bridges are theoretically designed to drain the water off the structure; nevertheless, possibly due to improper construction, a certain amount of it remains, lying mainly at the curbs and also in the joints. Sealers should be designed to recess 1/4" to 3/8" below the top of deck, though sometimes, regrettably, they are now being placed as much as 3/4" below the top surface, as again observed in the field. In winter, snow cleared off the roadways is piled up on the sidewalks with considerable concentration of salt. As outlined before, this moisture just lies there until it either leaks through a joint or evaporates.

During the freeze and thaw periods it is only natural for this moisture to work its way down carrying large concentrations of salt solution with it. Once such channels are established they provide the only way for water to escape from the trap.

Figure 8 illustrates the practices outlined in the preceding discussion.

Figures #9a and #9b represent the modified solution of the same details. It is not an ultimate answer to the problem, merely an attempt to remedy the present situation and is based on the experiences collected to date. The sealer is placed in the deck out-to-out simply because this part of the superstructure is where it is most likely to function properly. The ends are sloped just enough to prevent the moisture produced by driving rain, etc. from penetrating the open ends of sealers where it could accumulate, freeze, and damage the sealer. The bent-down ends also will encourage the flow of water out of the joint, whether it is driven there or leaks in, possibly, at the bottom of the curb. At present there is no known effective way to close the open ends of a sealer. The pocket for the end of the sealer, while not too deep to present difficulties for installation, is meant to prevent the sealer from straightening and migrating. There are indications that sealers in the skewed joints are induced to migrate, as it will be shown later.

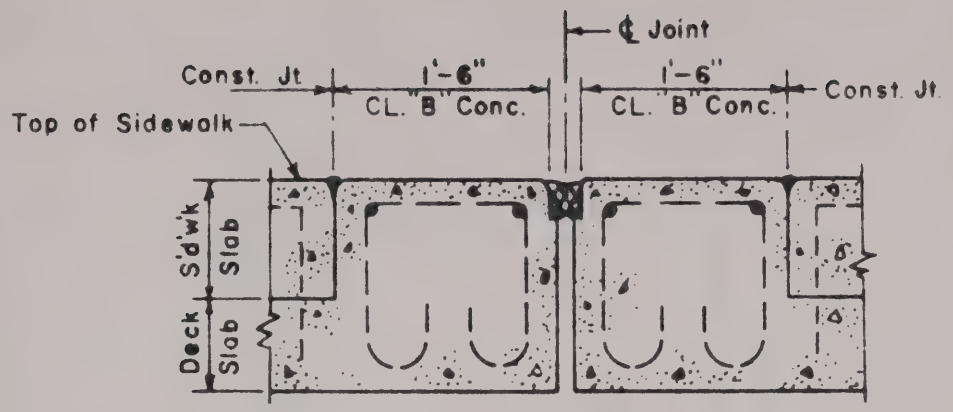


FIG. 8B

SECTION A-A

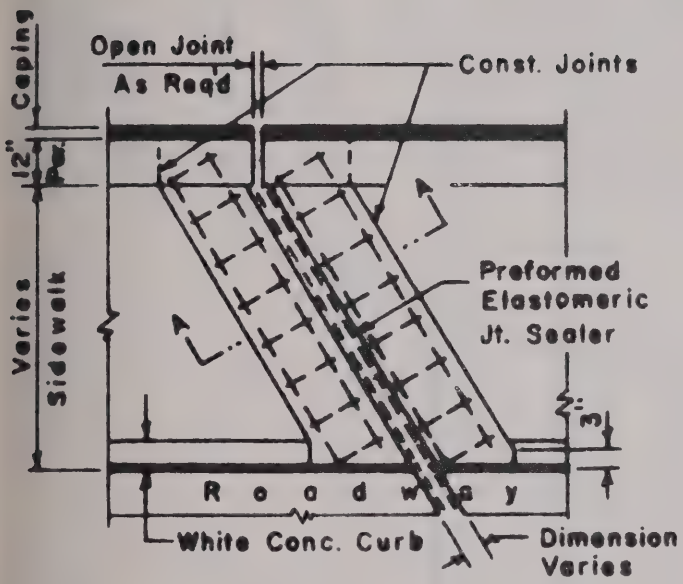


FIG. 8A

PLAN

Joint Sealing Detail
In Sidewalk Location

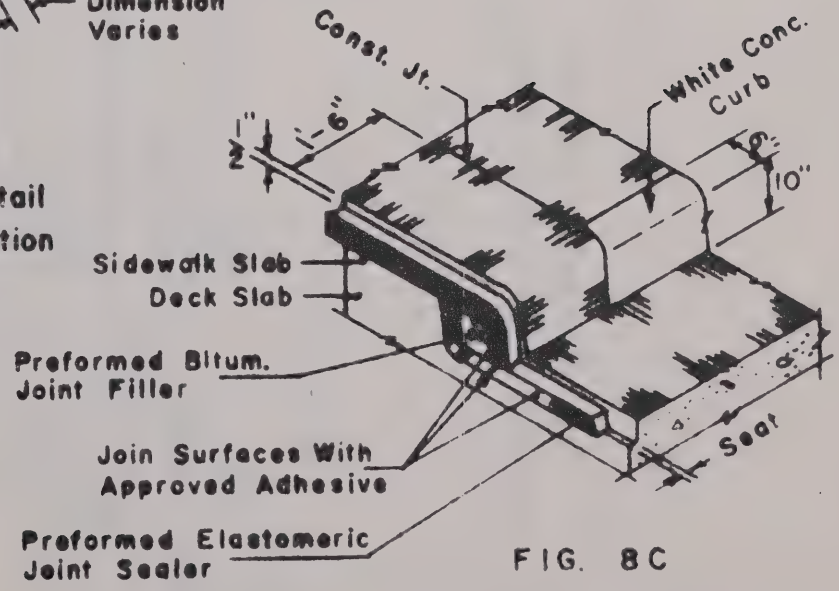
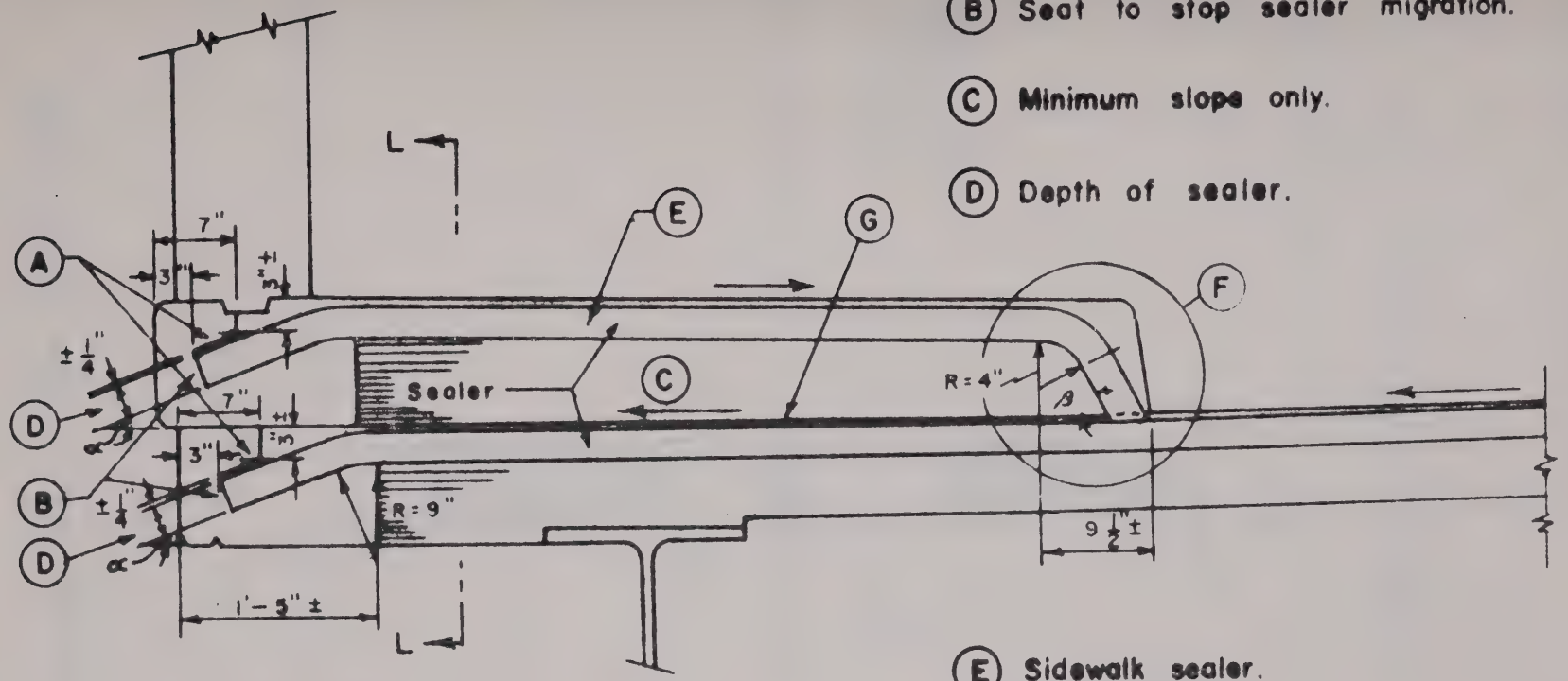


FIG. 8C

ISOMETRIC

FIG. 8



ELEVATION

Preformed Elastomeric Joint Sealer
Sidewalk Location

(A) Stay-in-place anchor seat use $\angle \alpha = 20^\circ$ to 30°.

(B) Seat to stop sealer migration.

(C) Minimum slope only.

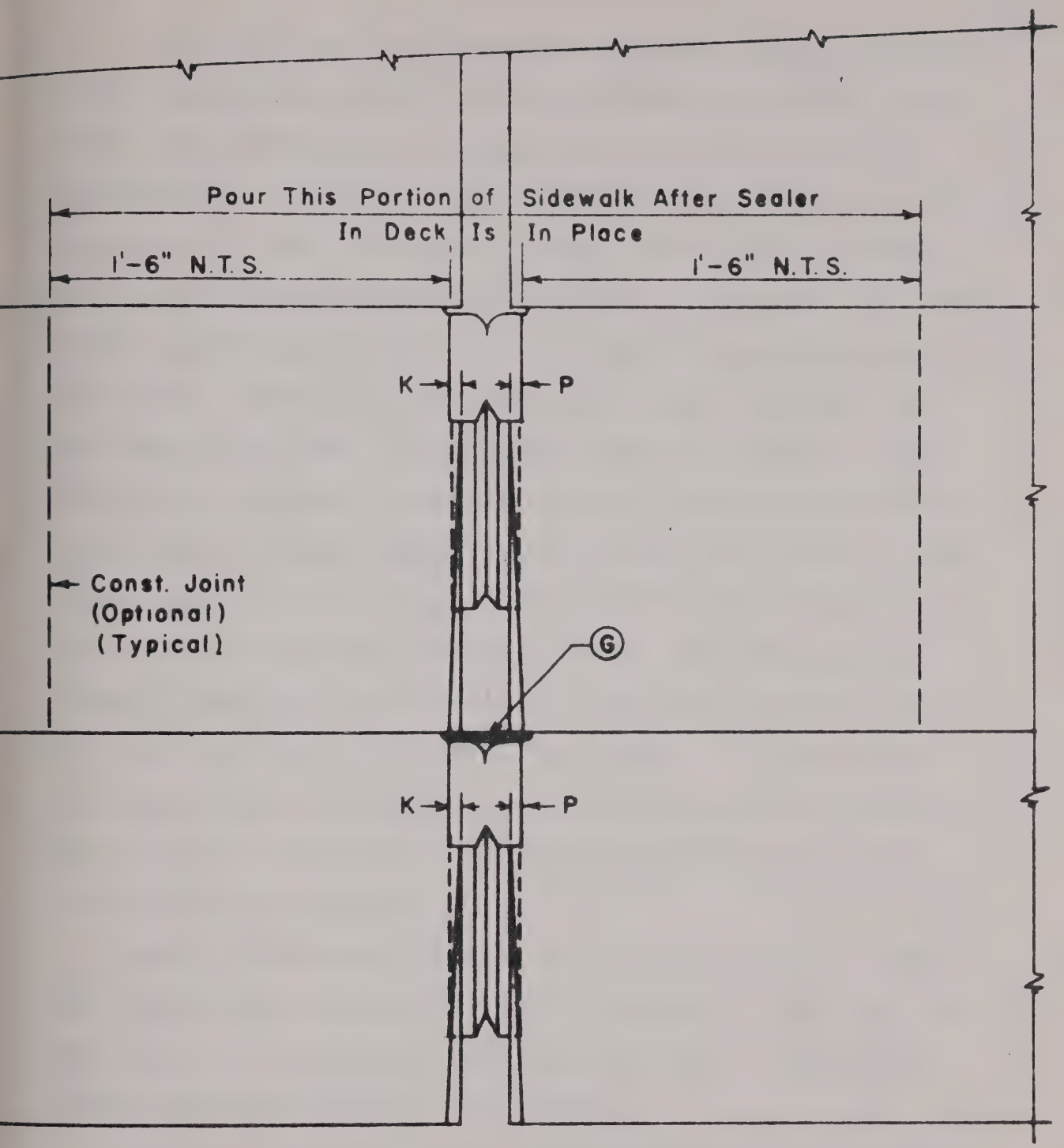
(D) Depth of sealer.

(E) Sidewalk sealer.

(F) Use $\angle \beta \leq 60^\circ$

(G) Place cork strip in joint before sidewalk is poured.

FIG. 9a



SECTION L-L

NOTE: Provide width of seat (K or P) = 1/4" or 3/8".

FIG. 9b

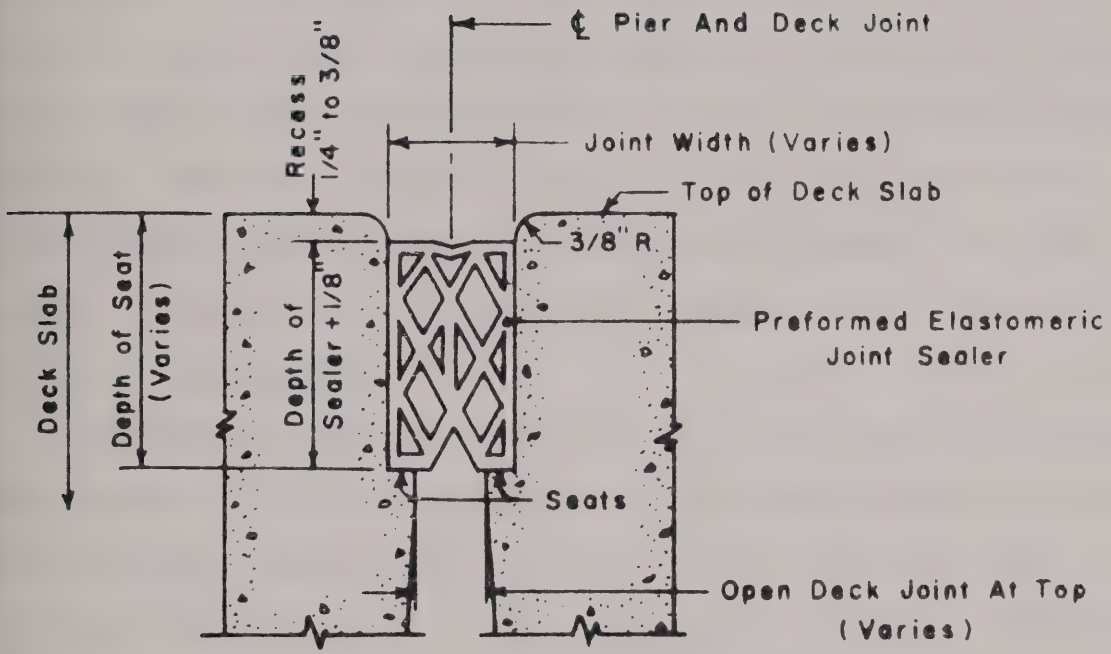
To date, we have not observed any actual sealer migration, perhaps because not enough time has elapsed since their installation. Or perhaps most probably, the resisting friction between sealer and joint sides is sufficiently strong to hold the sealer in place, the rubber itself elastically consuming the induced deck-end movements. If this is the case, the seats supporting the sealer ends could be simplified even more at a later date. Anyhow, by extending the sealers to almost the very face of the deck, it is hoped to prevent damage to the vital under-structure of the bridge deck by leading the water out and away from the joints before it gets the chance to leak through them. In this detail, the sealer in the sidewalk is there mainly to prevent foreign material from entering the sidewalk joints and to minimize the amount of moisture that will reach the outside faces of the bridges. To facilitate the installation and functioning of sealers in the sidewalk, positive seats throughout and the other modifications shown in Figure 9a are suggested.

Large size sealers are very difficult to install properly when considerable bending of them is required. Once they are bent there is no guarantee they will stay bent, unless they are mechanically prevented from moving.

Obviously, in this detail, the sealer has to be installed in the deck prior to pouring the sidewalk in the vicinity of the joint. To prevent grout from accumulating on the top of the deck sealer a protective strip of any flexible material, preferably cork, should be used.

The slope of the sealer-bend in the curb as shown in Figure 9a, is derived from observations.

Normally the sealer is located in the joint near the top of the deck; in its construction, seats are provided at an appropriate depth and the width of joint required by sealer design is made available. At present the required width of many sealer seats is 5/16 or 9/16 of an inch. This is an impractical dimension, for there is no such standard width of lumber or any other suitable material available for the construction of forms. For illustration of the above, see Figure 10 hereafter.



Deck Joint

FIG. 10

It is obvious that seals, in order to function properly, have to be located in a joint near the top of the deck. They must be recessed for protection from damage due to traffic. On the other hand, too deep a recess would allow for accumulation of excessive amounts of foreign material; this could become an incompressible mass, possibly damaging to the integrity of the joints. As a result of the above analysis, and on the basis of experience, the sealer should be recessed 1/4 to 3/8 of an inch instead of the present 1/2 inch requirement of New Jersey. When the sealer is placed in this way, the larger particles of foreign material will usually bounce off the sealer's surface and whatever will remain in the joint will be of no consequence.

The recess and the seats also are furnished to minimize the chance of vertical migration of the sealers due to downward pressure exerted by vehicles. Seats moreover serve as an excellent deterrent of the tendency to place the sealers at an excessive depth.

Present New Jersey applied design practices are as follows:

Span	Open Deck Joint Width	Width of Joint at Sealer @ 68°F	Sealer Size
Not to exceed 100 ft.	1"	1-5/8"	2½" x 2-3/4"
Not to exceed 150 ft.	1½"	2-5/8"	4" x 4-3/4"
Fixed Joint @ Pier	½"	1"	1-3/4" x 2"

The temperature range specified for the design of bridges is -20°F to +120°F. This seems to be adequate, when maximum air temperature range is considered. But the bridge deck end-movements are governed by the temperature of the concrete. It was therefore concluded, after a study of the thermal characteristics of bridge slabs, that the realistic effective concrete temperature range should be 0°F to 100°F.

This means only that the effective concrete temperature, which really governs the end-movements, should not be expected to drop below 0°F or to rise above 100°F.

The temperature of 68°F, at which the width of the joints is determined, is unfortunately impractical. In the actual construction there is no way to adhere to such a requirement. To mention just a few reasons: to date there is no way of determining such an effective concrete temperature, nor to hold to it throughout the construction of the joints and the installation of the sealers.

To overcome this difficulty as we did in the case of the general temperature range, we suggest to use a temperature range of the concrete of +30°F to +90°F during the construction of joints and the installation of sealers, these temperatures being both more realistic and more flexible.

When the actual effective concrete temperature, in construction and/or installation, is not known, it is suggested to adhere to the daily average temperatures of the air at the location of the construction, assuming that the effective temperature of the concrete is 5°F higher in the summer and

possibly 10°F higher in the winter months. Regarding these temperature tolerances, one must be careful not to overlook the effects of prolonged periods of cold or hot spells. Here, as in the whole concept of thermal effects, further study is essential.

Because of the seasonal boundaries in construction, the +30°F temperature limit is obviously not as critical as the 90°F restriction. This upper limit is chosen by reason of the difficulties encountered in construction and installation at higher than +90°F temperatures, plus the fact that the suggested range is already extremely large. This wide temperature range allows for less freedom in the design of joints and sealers than do the present requirements; the existing construction practices compel us nonetheless to resort to such a recommendation.

This discussion leads us to the analysis of the proposed New Jersey Standards Tables #2 and #3 (repeated for convenience on pages 74 and 75) and to the methods of construction of bridge joints.

The present method of developing the required joint is to actually form it. Regrettably, two basic reasons make this method inefficient.

No matter how accurately the joints are formed, they appear to open by as much as 1/8 of an inch, possibly more, during the concrete setting period. This has been established by observations, on the basis of the available data.

Far more serious is the problem of inadequacy of quality controls in construction practices.

Almost without failing, the actual dimensions of joints vary from the design by as much as 1/8", often 1/4" or even more, in the width of the joints; and up to 2" in the depth at which the sealer seats are located. These errors can and do happen within one and the same joint, i.e. it may be at one end 1-3/8" wide, and several feet away as much as 1-5/8" or more.

In essence, it means that the erroneous results (excessive width of joints) will actually cause a condition where $X_{max} > 0.7\ W_n$.

An example for illustration only:

If the span L = 65 ft, $\Delta t = 70^o$ or 90^o, and $W_n = 2\frac{1}{2}$", we should have at installation, W_j = 1-3/8" (see Table 2).

Now, suppose, that as a result of contraction of the concrete and/or an error in construction, W_{jinst} = 1-5/8".

Then

$$Y_{inst} = \frac{1.625}{2.5} = 0.65W_n > 0.55W_n$$

$$Z_{min} = \frac{1.625-0.30}{2.5} = 0.53\ W_n > 0.43W_n$$

and

$$X_{max} = \frac{1.625 + 0.39}{2.5} = 0.81W_n > 0.71W_n$$

PROPOSED NEW JERSEY STANDARDS (for present practice) - TABLE #2

Temperature Range: 0^{o} to 100^{o}F
Construction Temperature: 30^{o} to 90^{o}F
Installation Temperature: 30^{o} to 90^{o}F
Degrees of Efficiency: (required)
$Z_{min} = 0.40\ W_n \pm$
$Y_{average} = 0.60\ W_n \pm$
$X_{max} = 0.70\ W_n \pm$

W_n	@100°F W_j	Z	Δ@ Δt=70°	@30° to 90°F W_j	Y	Δ@ Δt=90°	@ 0°F $W_{j_{max}}$	X	Limits of Span
1½"	0.875	0.58	0.0	7/8"	0.58	0.0	0.875	0.58	Up to
	0.86	0.57	0.16			0.21	1.085	0.725	35'
1¾"	0.84	0.48	0.16	1"	0.57	0.21	1.21	0.69	35' to
	0.79	0.45	0.21			0.27	1.27	0.725	45'
2"	0.915	0.46	0.21	1-1/8"	0.56	0.27	1.395	0.70	45' to
	0.895	0.45	0.23			0.30	1.425	0.715	50'
2½"	1.145	0.46	0.23	1-3/8"	0.55	0.30	1.675	0.67	50' to
	1.075	0.43	0.30			0.39	1.765	0.71	65'
3"	1.45	0.48	0.30	1-3/4"	0.58	0.39	2.14	0.71	65' to
	1.38	0.46	0.37			0.475	2.225	0.74	80'
4"	1.88	0.47	0.37	2¼"	0.56	0.475	2.725	0.68	80' to
	1.74	0.435	0.51			0.65	2.90	0.725	110'
5"*	2.24	0.45	0.51	2-3/4"	0.55	0.65	3.40	0.68	110' to
	2.15	0.43	0.60			0.77	3.52	0.70	130'
6"*	2.775	0.46	0.60	3-3/8"	0.56	0.77	4.145	0.69	130' to
	2.615	0.435	0.74			0.95	4.325	0.72	160'

NOTE: All the above temperatures are those of the concrete. Since these temperatures cannot readily be measured, the daily average temperature of the air with a tolerance of +5 to +10°F would be presently acceptable.

* Because of the lack of experience with these two largest sizes, it is preferable not to use the sealer widths W_n = 5" and 6" until further data are available.

PROPOSED NEW JERSEY STANDARDS (for revised practice) - TABLE #3

Temperature Range: 0^{o} to 100^{o}F
Construction Temperature: 30^{o} to 90^{o}F
Installation Temperature: 30^{o} to 90^{o}F
Degrees of Efficiency: Z_{min} = 0.40 $W_n \pm$
$Y_{average}$ = 0.60 $W_n \pm$
X_{max} = 0.80 $W_n \pm$

	@100°F		Δ@	@30° to 90°F		Δ@	@ 0°F		
	$W_{j_{min.}}$	Z	$\Delta t=70^{o}$	W_j	Y	$\Delta t=90^{o}$	$W_{j_{max.}}$	X	Limits of Span
"	0.875	0.58	0.0	7/8"	0.58	0.0	0.875	0.58	Up to
	0.621	0.41	0.254			0.327	1.202	0.80	55.0'
."	0.746	0.43	0.254	1"	0.57	0.327	1.327	0.75	55.0' to
	0.700	0.40	0.300			0.386	1.386	0.79	65'
	0.825	0.41	0.300	1-1/8"	0.56	0.386	1.511	0.76	65.0' to
	0.778	0.39	0.347			0.446	1.571	0.79	75'
⅛"	1.153	0.46	0.347	1½"	0.60	0.446	1.946	0.78	75' to
	1.084	0.43	0.416			0.535	2.035	0.81	90'
"	1.334	0.44	0.416	1-3/4"	0.58	0.535	2.285	0.76	90' to
	1.242	0.41	0.508			0.653	2.403	0.80	110'
"	1.867	0.47	0.508	2-3/8""	0.59	0.653	3.028	0.75	110' to
	1.682	0.42	0.693			0.891	3.266	0.81	150'
"*	2.182	0.44	0.693	2-7/8"	0.57	0.891	3.766	0.75	150' to
	1.951	0.39	0.924			1.188	4.063	0.81	200'
"*	2.576	0.42	0.924	3½"	0.58	1.188	4.688	0.78	200' to
	2.484	0.41	1.016			1.307	4.807	0.80	220'

OTE: All the above temperatures are those of the concrete. Since these temperatures cannot readily be measured, the daily average temperature of the air with a tolerance of +5 to +10°F would be presently acceptable.

* Because of the lack of experience with these two largest sizes, it is preferable not to use the sealer widths W_n = 5" and 6" until further data are available.

The main consequence of the limitation of joint widths is that sealers have to be larger for shorter spans, resulting in an increase in sealer cost. At the same time, the total upper limit of the bridge span is considerably lowered, to as little as 110 ft. for 4 inch sealers, the maximum size usable to date.

The other feature of Tables #2 and #3 is the breaking down of the ranges of the span length into small increments. This automatically introduces a factor of unpredictable movements into the design and allows for economy in sealer costs.

We have shown the handicaps in the presently utilized methods of joint construction. In order to improve the results we recommend the use of two other methods. Their performance data are not available to us, but both are already in limited use in other states and in Europe.

Before we discuss the alternative methods, it should be indicated that by utilizing metal forms at the joints the results could be greatly improved.

By attaching these forms to beams, the fluctuation of temperatures could be overcome and the width of the joints could be related to the temperatures at the time of construction. The difficulty, of course, is that these forms will have to be slim enough to fit into narrow joints; independently on each side of the joint, yet strong enough to obtain an accurately developed joint throughout the full length.

The FIRST ALTERNATE METHOD is based on sawing the joints. This is how it can be executed: The open deck joint, or basic joint determined by design, is formed by normal means. As soon as practical, the upper portion of the joint, where the sealer will be located (seal groove), is saw-cut to the required depth of the sealer seats. This is done in one continuous operation throughout the full width of the deck, excepting, naturally, the very ends, as Fig. 9a indicates.

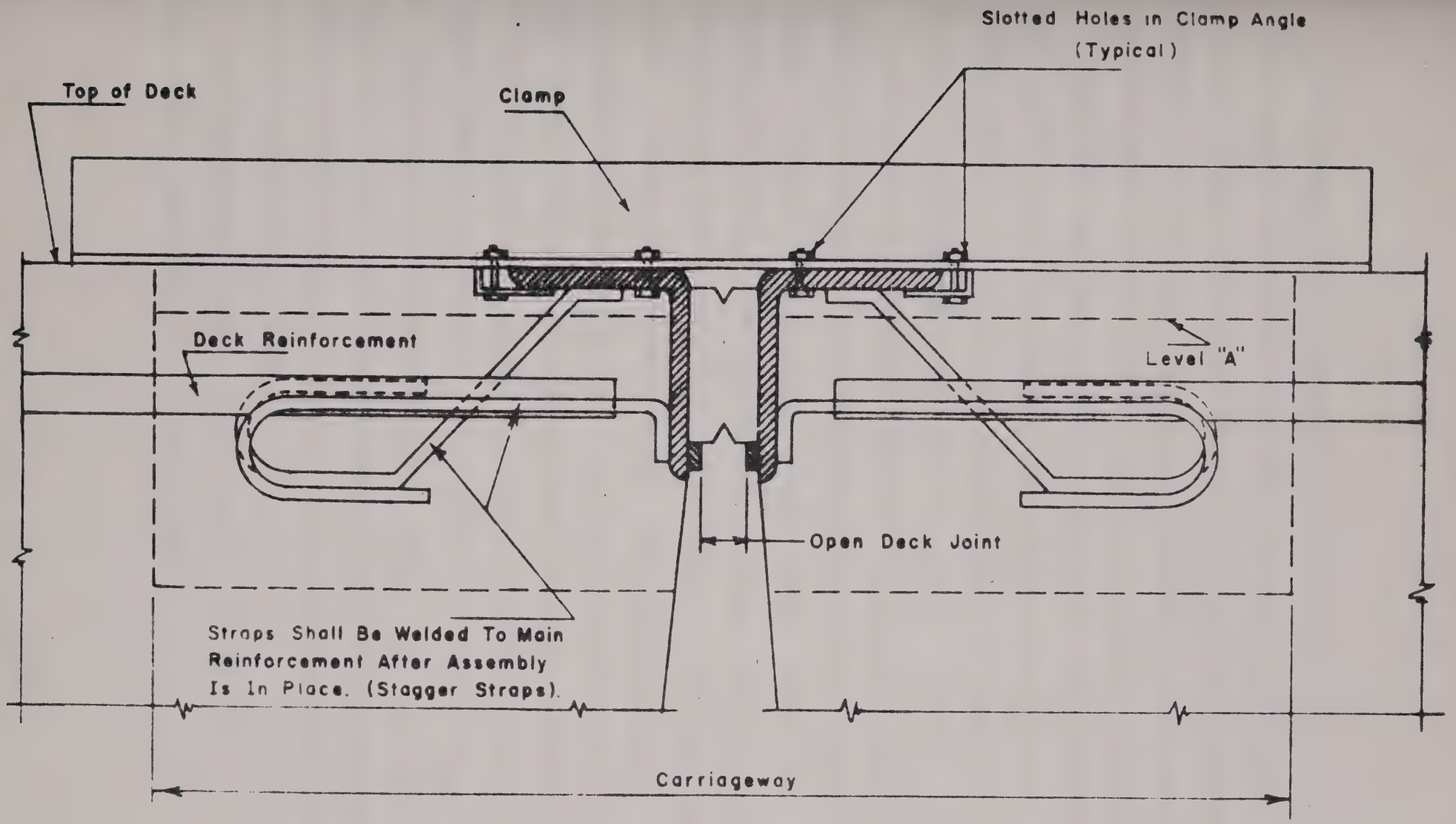
To achieve smooth and even seal-seating-ledges, insert a chisel of 3" minimum width in the saw-cut and use the chisel as a lever to break the concrete at the ledges. Remove the broken concrete and clean the joints. The accuracy of the seal-grooves thus achieved could be held within ±1/16", which is adequate. In a sidewalk the seal-groove could be saw-cut in the same manner except at the curb and the very outside, as shown in Fig. 9a. If preferred, the present method of construction could be retained in sidewalk construction, since once the deck is properly sealed, the sealing of the sidewalk is of no great importance.

This method of construction is being suggested in the State of Pennsylvania. One drawback in this process is a possible increase in the cost of joint construction; it would be offset by the use of smaller size seals, since the proposed New Jersey Standards (Table #3) are applicable to this type of joint construction. A second drawback is the probable spalling of the sides of the joints due to traffic, as presently observed and to be described later.

The SECOND ALTERNATE METHOD of construction is armored joints.

This method, as utilized in Europe, is well illustrated in the Swiss brochure on "Proceq processes and equipment". Their type of sealer is different and their armor method is complex; nevertheless, the basic design principle is perfectly applicable to our circumstances.

Figure #11 illustrates the idea of armored joints under our conditions.



Armored Joint Detail

FIG. 11

The concept of this method is that the whole system (armor angles with straps and seats welded to them, sealer properly precompressed between the angles and the supporting elements, such as clamps and attached bolts) is preassembled and then placed into the joint before the concrete is poured.

There are many ways of doing the above. The procedure used should satisfy the design requirements on the one hand; on the other, it must give the fullest possible consideration to the de facto construction practices.

On this basis, the best approach would be to have the elements of the system preassembled to the fullest practicable degree, delivered to the construction site and there the assembly completed. The deck should be poured so as to leave the necessary recess with deck reinforcement properly extended into it. After the concrete is set, the assembly can be placed into the recess, properly located, and the width of the joint between the armor angles adjusted in accordance with the design requirements; then the bar-straps should be welded to the main deck reinforcement. The recess should be filled to the level "A" with optimum-packed-up concrete of good quality. After the concrete in the carriageway is set, the supporting elements should be removed and the surfacing of the deck at the joint carefully completed.

This procedure, with a little care in construction, should give a satisfactorily sealed joint.

As in the first alternate method, the armored deck joints should be continuous throughout the full width of the deck, and termination should be accomplished in the same fashion as shown in Fig. 9a; of course the stay-in-place anchor and the stop seats should be executed in metal. It is obvious that the angles are utilized for a dual purpose: to armor the joints where necessary, and to form the best sealed joint possible.

The seal-groove in the sidewalk could also be armored in the same manner, with the curb and outside ends installed as indicated in Fig. 9a. But a stay-in-place anchor seat could be added in the curb end at the bottom outside face of the armor angles. However, if preferred, the present method of construction could be retained, as in the case of the saw-cut joints.

Proposed New Jersey Standards - Table #3 - is also applicable to this type of joint construction.

Table #3 really differs very little from Table #2 and is self-explanatory.

By raising the upper limit of X_{max} to $\pm 0.8W_n$ we are able to use smaller sealers for longer spans. Concerning everything else in Table #3, please refer to prior comments.

The only obvious drawback of the armor joint construction, as outlined in this paper, is cost. It is, without doubt, the most expensive method, but being practically an ultimate

solution for sealed-joint construction, it is worth its expense as outlined in our "Discussion of Cost Analysis".

By "ultimate solution" we mean that initial set, creep, thermal effects, and installation of sealers are in this way satisfactorily resolved.

It can also be expected that the cost of the solution offered above will compare quite favorably to the Swiss patent mentioned previously.

In reference to "fixed joints" our observations have indicated the possibility of the application of the smallest size sealer practicable, but caution must be exercised in determining so-called "fixed joints".

D/ RESEARCH DATA

As already mentioned, more than once, the correlation between theory and laboratory on one hand, and the actual conditions and behavior of sealers in field applications on the other, is of the utmost importance. This is why considerable emphasis has been placed in this project on the observation of the various aspects of the actual utilization of sealers. The methods of observation used will be described in a special section; here we will talk about the results.

During the period from May 1965 to date, seventeen (17) bridges were observed in New Jersey. For most of them our observations started shortly before sealer installation; they continued during installation and periodically later on, in order to gather data on joints and sealers in actual use. Arbitrary numbers are given to each bridge discussed.

The first step was to collect data on bridges under construction, where the subject seals were to be utilized; next, contact with our field personnel had to be established, so that the construction schedule could be closely followed. This was necessary for the purpose of correlating our schedule of observations with the work program in the field. Due to the difficulties of practical operations we were not always able to choose the most suitable structures. Nevertheless, the geographic locations of the observed bridges are well distributed throughout the State, from north to south, and

along the coast. The procedure generally adopted was as follows:

First, the Bureau's research field force was dispatched to the bridge prior, and as close in time as possible, to the date of sealer installation. Their immediate tasks were to install measuring devices; to perform necessary measurements; and to observe joint construction conditions.

On the day of the sealer's placement the Engineer in charge of the research project, assisted by the field group, was present on the job. Also present were: the Highway Department's field personnel, the contractor's men in charge of the construction, and often distributor's or supplier's representatives. This time measurements were made again. Construction and installation practices, methods and conditions were closely observed, in most cases, throughout the whole procedure.

The day of primary measurements was usually established as the initial date for recording the field observations; the data collected were later analyzed and plotted on graphs, similar to Graphs #1 to #12.

The observations and measurements by our field force were continued periodically on a selected number of bridges following a more or less regular schedule, starting in January 1966. The schedule included a total number of fourteen (14) structures, distributed in four groups determined by their geographical locations.

Specific Initial Observation Data

The period to January 1966 was devoted to initial observations summarized in Tables #9.1 to 9.8.

Explanation of typical abbreviations in these Tables:

"Expansion Joints at N & S Abutments, W & E", means: Expansion joints located at North and South abutments, plug installation placed at West and East ends of the joints.

B(K) indicates a sealer manufacturer "B" and product patent "K", as explained previously.

Table #9.1

Summary of Data from Initial Observations

Bridge No. 15a & c, skewed

Rt. 17, Sec. 5C, Northern New Jersey

Sealer Manufacturer and Product Patent: B(K)

Bridge 15a: Expansion Joints at N. & S. Abutment, W. & E.

Fixed Joint at Pier.

Bridge 15c: Expansion Joint at N. Abutment, W. & E.

Fixed Joint at S. Abutment W. & E.

Date of Plug Installation: 10-14-65

Date of Sealer Installation: 10-27-65

Designed Joint Dimensions (W x H*): Bridge 15a Joint at Pier: 1" x 2½"
All other joints: 1-5/8" x 3-3/8"

Joint As-Built Dimensions (W x H): ** Bridge 15a Joint at Pier:
1-9/16" x (2¼" to 2½")
All other joints: (1-3/4" to 1-7/8") x (3" to 3½")

Nominal Sealer Size (W x H): Bridge 15a Joint at Pier: 1-3/4" x 2"
All other joints: 2½" x 2-3/4"

Actual Sealer Size (W x H): ** Bridge 15a Joint at Pier: 1-3/4" x 1-15/16"
All other joints: (2-3/4" to 2-7/8") x 2-3/4"

Sealer Placed In Joint: Some parts of top of sealer are above top of concrete or are ¼" to 3/8" below it.

Joints As-Built Condition: Seats are irregular or missing, W and H are irregular, sides are sloping. In general, joints are sloppy, dusty, and in some places spalled. Top of deck elevations at joints are also irregular.

Sealer Condition: Somewhat irregular in width and height.

(more)

'ints' Forms: Bridge 15a Joint at Pier: No data.
All other joints: 2" x 4" lumber

Note: W = Width H = Height

The numbers indicated are samples of the variations from design dimensions which have occurred in some cases; they are not necessarily representative, typical, or average values.

Table #9.2

Summary of Data from Initial Observations

Bridge No. 3a, skewed

Rt. 287, Sec. 11A & 12C, Northern New Jersey

Sealer Manufacturer and Product Patent: B(K)

Fixed Joint #1 S-W & S-E

Expansion Joint #2 N-E & N-W

Date of Plug Installation: 6-16-65

Date of Sealer Installation: None

Designed Joint Dimensions (W x H*): 1-5/8" x 3-3/8"

Joint As-Built Dimensions (W x H): ** Joint #1 (1-5/8" to 1-11/16")
Joint #2 (1-3/4" to 1-15/16")
(No data available on H)

Nominal Sealer Size (W x H): 2½" x 2-3/4"

Actual Sealer Size (W x H): No data.

Sealer Placed in Joint: Some parts of top of sealer are above top of concrete in Joint #1;
For Joint #2, no data.

Joint As-Built Condition: For Joint #1, no data.
In Joint #2, poor edging of joints and some spalling.

Sealer Condition: Not continuous; in sections of 10' to 12'
(See Photos #1 and #2)

Joints' Forms: No data.

---

* Note: W = Width H = Height

** The numbers indicated are samples of the variations from design dimensions which have occurred in some cases; they are not necessarily representative, typical, or average values.

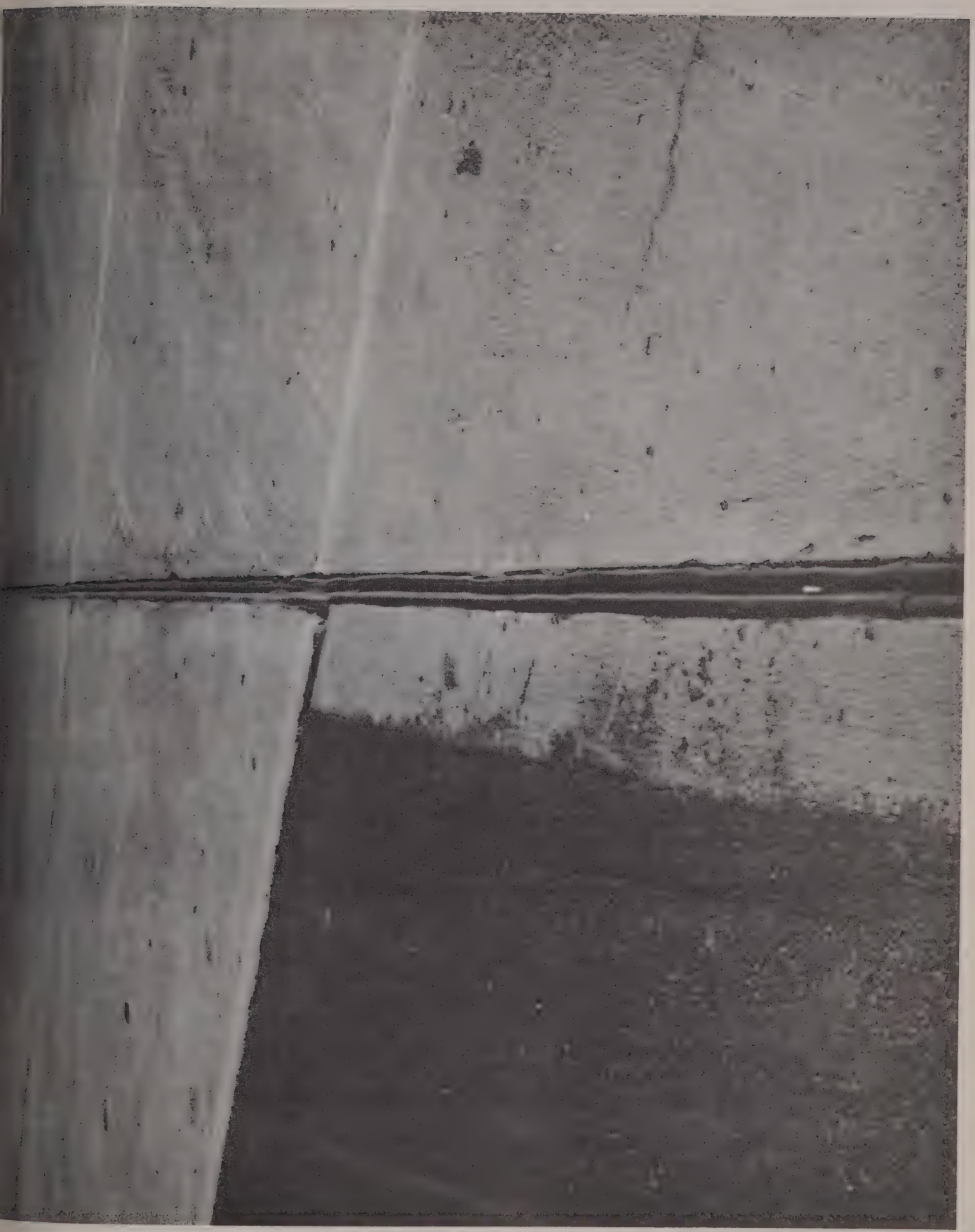


PHOTO NO. 1
Sealer and Joint Conditions
Bridge No. 3a

PHOTO NO. 2
Non-Continuous Sealer.
Bridge No. 3a

Table #9.3

Summary of Data from Initial Observations

Bridge No. 9b, skewed

Rt. 287, Sec. 6E, North Central New Jersey

Sealer Manufacturer and Product Patent: A(K)

Expansion Joint #1 N-E & S-E

Expansion Joint #2 N-W & S-W

Date of Plug Installation: 7-13-65

Date of Sealer Installation: 7-13-65

Designed Joint Dimensions (W x H*): 1-5/8" x 3-3/8"

Joint As-Built Dimensions (W x H): ** Joint #1: (1½" to 1-5/8") x (3⅛" to 3½")

Joint #2: (1½" to 1-13/16") x (3¼" to 3½")

Nominal Sealer Size (W x H): 2½" x 2-3/4"

Actual Sealer Size (W x H): ** Joint #1: 2-5/8" ± x 2-27/32" ±

Joint #2: (2-9/16" to 2-13/16") x 2-3/4" ±

Sealer Placed in Joint: Recessed by ¼" to 3/8"

Joints As-Built Condition: Joints are irregular, their sides are honey-combed, rough and dusty. Top of deck elevations at joints are also irregular. Also, Joint #2 is slightly slanted.

Sealer Condition: For Joint #1, no significant data. In Joint #2, the sealer is somewhat irregular.

Joints' Forms: No data.

---

* Note: W = Width H = Height

** The numbers indicated are samples of the variations from design dimensions which have occurred in some cases; they are not necessarily representative, typical, or average values.

Table #9.4

Summary of Data from Initial Observations

Bridge No. 10b

Rt. 287, Sec. 6F & 7B, North Central New Jersey

Sealer Manufacturer and Product Patent: B(K)

Expansion Joint #2 N-E & N-W

Expansion Joint #3 E. & W.

Expansion Joint #4 S-E & S-W

Joints #1 & #5.

Date of Plug Installation: Joints #1 & 5: None
Joint #2: 6-24-65
Joints #3 & 4: 6-23-65

Date of Sealer Installation: 6-24-65

Designed Joint Dimensions (W x H*): 1-5/8" x 3-3/8"

Joint As-Built Dimensions (W x H): ** Joint #2: (1-11/16" to 1-3/4") x (4¼" to 5")

Joint #3: (1-9/16" to 1-13/16") x 5½±

Joint #4: (1-3/4" to 1-13/16") x (4" to 5¼")

Joint #1: (1-11/16" to 1-7/8") x 3½"

Joint #5: (1-11/16" ±) x (3-3/8" to 3½")

Nominal Sealer Size (W x H): 2½" to 2-3/4"

Actual Sealer Size (W x H): ** (2½" to 2-7/8") x (2-3/8" to 2½)

Sealer Placed in Joint: Recessed by ¼"±

Joints As-Built Condition: Joints are somewhat damaged and their sides are honey-combed.

Sealer Condition: Somewhat irregular and at the curb the sealer's undercut is irregular, except no undercut in sealers in joints #1 and #3 to 5.

Joints' Forms: No data.

---

* Note: W = Width H = Height

** The numbers indicated are samples of the variations from design dimensions which have occurred in some cases: they are not necessarily representative, typical, or average values.

Table #9.5

Summary of Data from Initial Observations

Bridge No. 7

Rt. 33, Monmouth Co., Coastal New Jersey

Sealer Manufacturer and Product Patent B(K)

Fixed W. Abutment S. & N.

Expansion E. Abutment N. & S.

Date of Plug Installation: 7-2-65

Date of Sealer Installation: 7-2-65

Designed Joint Dimensions (W x H*): 1-5/8" x 3-3/8"

Joint As-Built Dimensions (W x H): ** (1-3/4" to 1-7/8") x (3-3/16" to 3-11/16")

Nominal Sealer Size (W x H): 2½" x 2-3/4"

Actual Sealer Size (W x H): ** (2-½" to 3") x (2-3/8" to 2½")

Sealer Placed in Joint: Recessed (3/8" to 11/16")

Joints As-Built Condition: Top of deck elevations at joints and W and H are irregular.

Sealer Condition: Irregular in width and height. At the S-W Abutment curb, the sealer's undercut is in "V" shape; others are as required and usually irregular.

Joints' Forms: No data.

---

* Note: W = Width H = Height

** The numbers indicated are samples of the variations from design dimensions which have occurred in some cases: they are not necessarily representative, typical, or average values.

Table #9.6

Summary of Data from Initial Observations

ridge No. 11a

t. 35, Keyport, Coastal New Jersey

ealer Manufacturer and Product Patent: No data.

ixed Joint #1 at Pier N-W & S-W

xpansion Joint #2 at Pier N-E & S-E

ate of Plug Installation: 6-11-65

ate of Sealer Installation: None

esigned Joint Dimensions (W x H*): 1" x 2½ at Joint #1
1-5/8" x 3-3/8" at Joint #2

oint As-Built Dimensions (W x H): Joint #1: (1-1/8" to 1¼")
Joint #2: (1-9/16" to 1-3/4")
No data available on H

ominal Sealer Size (W x H): Joint #1: 1-3/4" x 2"
Joint #2: 2½" x 2-3/4:

ctual Sealer Size (W x H): No data.

ealer Placed in Joint: Some parts of top of sealer were above top of concrete.

oints As-Built Condition: No data.

ealer Condition: No data.

oints' Forms: No data.

Note: W = Width H = Height

* The numbers indicated are samples of the variations from design dimensions which have occurred in some cases; they are not necessarily repreesentative, typical, or average values.

Table #9.7

Summary of Data from Initial Observations

Bridge No. 17 a to f

Rt. 295, Sec. 1N, Southern New Jersey

Sealer Manufacturer and Product Patent: A(K)

Bridge 17a Joints: #1 (Abutment) N-E & N-W
*** #2 S-E & S-W

Bridge 17b Joints: #1 (Abut.) N-E & N-W
#2 S-E & S-W

Bridge 17c (skewed)
Joints: #3 N-E & N-W
#4 (Abut.) S-E & S-W

Bridge 17d Joints: #3 N-E & N-W
#4 (Abut.) S-E & S-W

Bridge 17e Joints #2 N-E & N-W
#3 S-E & S-W

Bridge 17f Joints: #2 N-W & S-W
#3 S-E & N-E

Date of Plug Installation: Br. 17a, c, d, e: 10-21-65
17b: 11-10-65 & 11-12-65
17f 9-20-65

Date of Sealer Installation: In the period of 10-29-65 to 11-12-65.

Designed Joint Dimensions (W x H*): 1-5/8" x 3-3/8"

Joints As-Built Dimensions (W x H) ** Br. 17a: (1-9/16" to 1-13/16") x (3¼" to 3-9/16")

17b: (1-3/4" to 1-15/16") x (3¼" to 3-3/4")

17c: (1-5/8" to 1-13/16") x (3-9/16" to 4")

17d: (1-3/8" to 1-7/8") x (3-1/16" to 3-21/32")

17e: (1-11/16" to 2-1/16") x (3-31/64" to 3-7/8")

17f: (1½" to 1-3/4") x (3½" to 3-23/32")

minal Sealer Size (W x H): 2½" x 2-3/4"

tual Sealer Size (W x H): ** (2½" to 2-5/8") x 2-3/4"

ealer Placed in Joints: Recessed 3/4" ±

oints As-Built Condition: Although the joints on these bridges were the best we have observed, some spalling, honey-combing, grout in joints and differential elevations of top of deck at joints were evident.

ealer Condition: Somewhat irregular.

oints' Forms: Effort was made to construct good joints by building up forms in layers, utilizing one layer of preformed filler and two layers of plywood. Attempt was made to form accurately the 5/16 of an inch seats.

Note: W = Width H = Height

* The numbers indicated are samples of the variations from design dimensions which have occurred in some cases: they are not necessarily representative, typical, or average values.

** All these are expansion joints.

Table #9.8

Summary of Data from Initial Observations

ridge No. 22, skewed

t. 18, Sec. 2A & 1C, North Central New Jersey

ealer Manufacturer and Product Patent A(K)

ixed Joint #1 E. Abutment S. & N.

xpansion Joint #2 W. Abutment S. & N.

ate of Plug Installation: 3-16-66

ate of Sealer Installation: 4-6-66

esigned Joint Dimensions (W x H*): 2-5/8" x 5½"

oint As-Built Dimensions (W x H): ** Joint #1: (2-13/16" to 2-15/16") x (5¼" to 5½")

Joint #2: (2-11/16" to 2-7/8") x (5¼" to 5-3/8")

ominal Sealer Size (W x H): 4" x 4-3/4"

ctual Sealer Size (W x H): ** Joint #1: (4-1/16" to 4-1/4") x (4-5/8" to 4-3/4")

Joint #2: (4" to 4-1/8"); No data available on H

ealer Placed In Joint: Recessed: ¼" to 5/8"

oints As-Built Condition: Joints look good, except for a spall at E. Abutment.

ealer Condition: Continuously extruded sealer, but somewhat irregular.

oints' Forms: No Data.

---

* Note: W = Width H = Height

** The numbers indicated are samples of the variations from design dimensions which have occurred in some cases; they are not necessarily representative, typical, or average values.

General Initial Observation Data

In the course of our scheduled studies, the following further data, common to most of the observed bridges, were gathered:

1. The sealers were furnished to the site coiled in continuous lengths, shop-vulcanized from 10 to 15 feet sections. On one occasion it was reported that a sealer, which had been stored over the winter in the cold, snapped at the shop-vulcanized joint, when it was unrolled on the site, still at a low temperature.

2. The lubricant-adhesive was applied, as a rule, on both sides of the joint. The placing of the sealers presented the least amount of difficulties when the adhesive was put on thoroughly for the full joint depth. When used on sealers and joints, the extruded adhesive marred the deck at joints as shown on Photograph No. 3. On the other hand, if an insufficient quantity of this material was used in the joints the difficulty of sealer installation proportionally increased. At least on one occasion, at an air temperature above 90°F, the adhesive was setting faster than the sealers could be normally placed. The air inside the sealers, trapped between vulcanizations, expanded, making the seals incompressible while the rubber became quite pliable. Obviously all these problems made seal placement difficult.

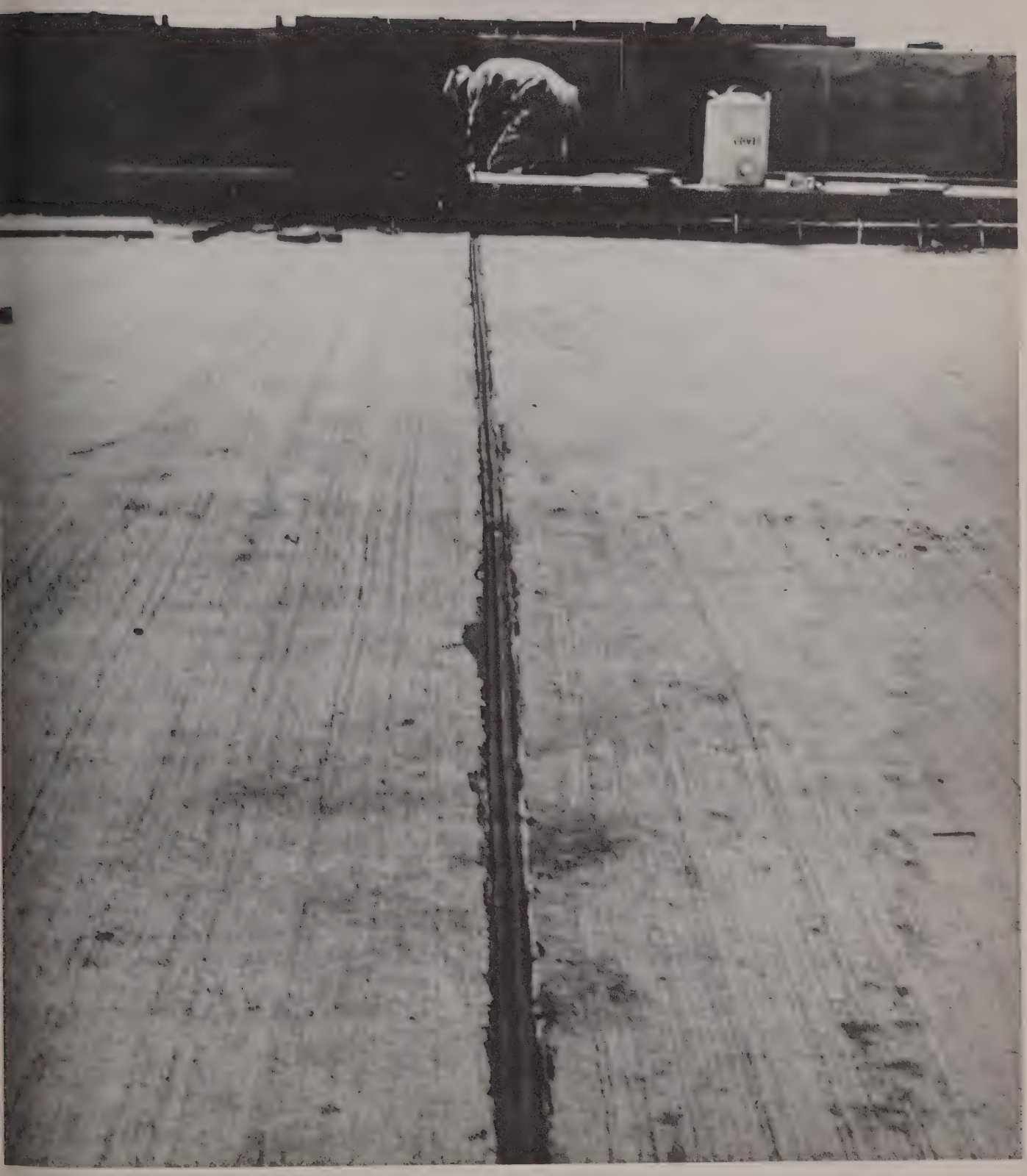


PHOTO NO. 3
Top of deck marred by lubricant-adhesive.

3. The tools provided to apply the lubricant and install the sealers are: brush, container, and placing bars, as shown in Photographs No. 4 to 8. Usually the brush was too soft to be effective. In one instance the manufacturer's representative suggested the use of a paint-roller, a method that failed almost immediately (see Photograph No. 9). A worn-down whisk-broom introduced thanks to a laborer's ingenuity, proved itself as more satisfactory than anything else. The bars used for placing the sealers are rather impractical for this purpose and are too often tools of destruction. To install sealers is not an easy physical task, and one cannot be very gentle while doing it. As a result, while rubber takes the abuse amazingly well, the concrete often is chipped and/or otherwise damaged.

There is a great deal of advertising concerning mechanical installation equipment. We requested further information from an "M" Company in reference to their pressure-operated tool, and from an "N" Company regarding the same kind of equipment. Regretfully, we did not receive any satisfactory reply from the first organization and the other one's equipment, besides being only a hand operated tool, requires a solution of soap and water as a lubricant. This solution is not compatible with present methods of sealer installation. Yet the urgent need for such an effective tool is apparent, unless present methods of sealer installation are drastically revised, as in the case of the armored joints outlined elsewhere in this report.

PHOTO NO. 4
The lubricant-adhesive is applied by means of a stiff-fibered "whisk-broom".

PHOTO NO. 5
The lubricant-adhesive is applied by means of a stiff-fibered "whisk-broom".

PHOTO NO. 6
The sealers are placed into joints by means of "placing bars".

PHOTO NO. 7
The sealers are placed into joints by means of "placing bars".

PHOTO NO. 8
Placing sealer on another bridge.

PHOTO NO. 9
Application of lubricant-adhesive by means of a paint roller.

4. The damages to the concrete, at joints, almost without exception, occur during the extraction of the forms from the joints. Although such joint injuries are supposed to be repaired prior to the installation of the sealers, their detrimental effects are apparent. Photographs No. 10 to 14 indicate injuries to the joints due to construction work and various already mentioned causes, other than regular traffic.

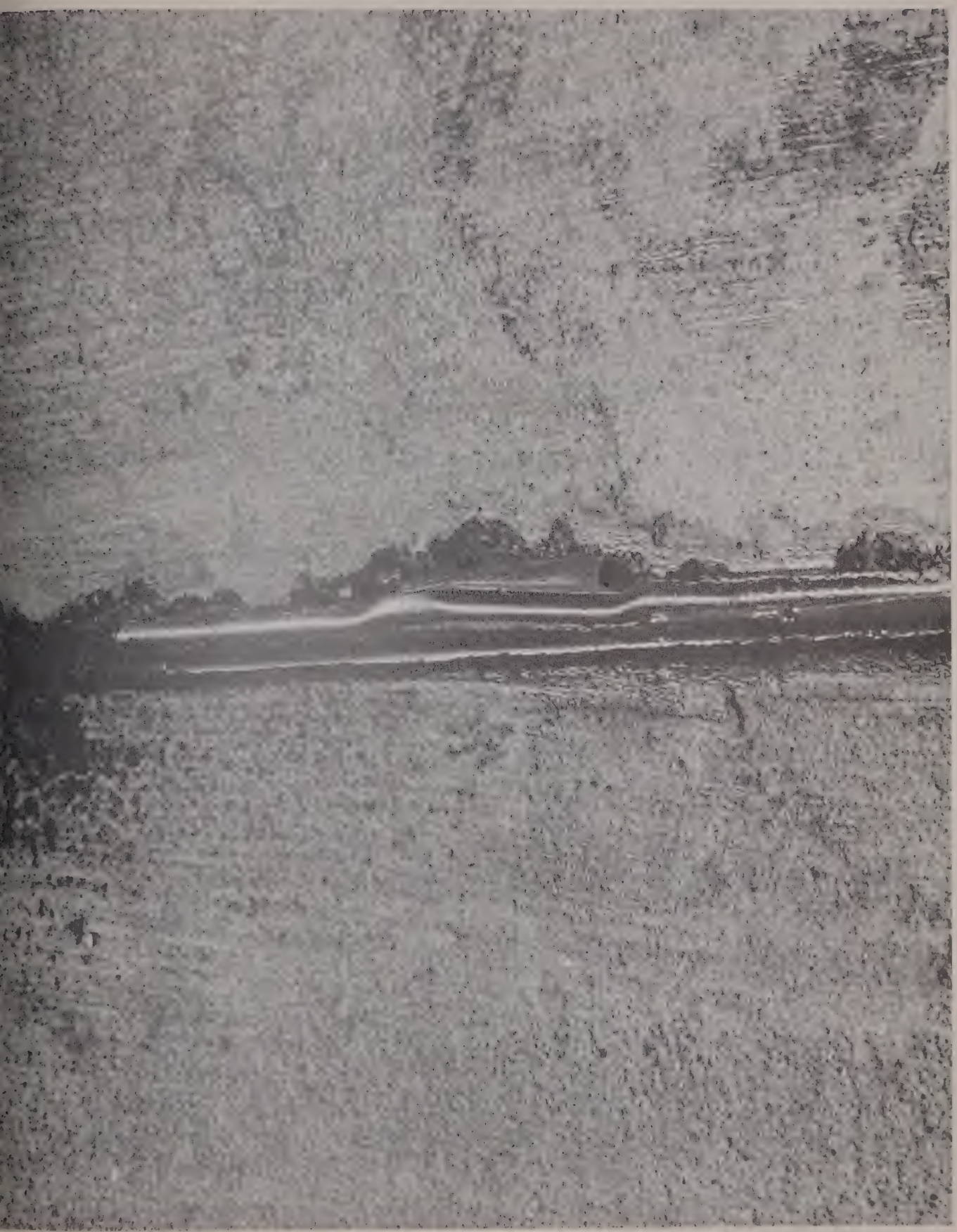


PHOTO NO. 10
Piece of wood is placed by "some-body" apparently
to substitute for spalled concrete.
Bridges No. 17a to f.

PHOTO NO. 11
This sealer is really "relaxed".
Bridges No. 17a to f.

PHOTO NO. 12
This sealer is also "relaxed".
Bridges No. 17a to f.

PHOTO NO. 13
Pencil indicates the spall.
Bridges No. 17a to f.

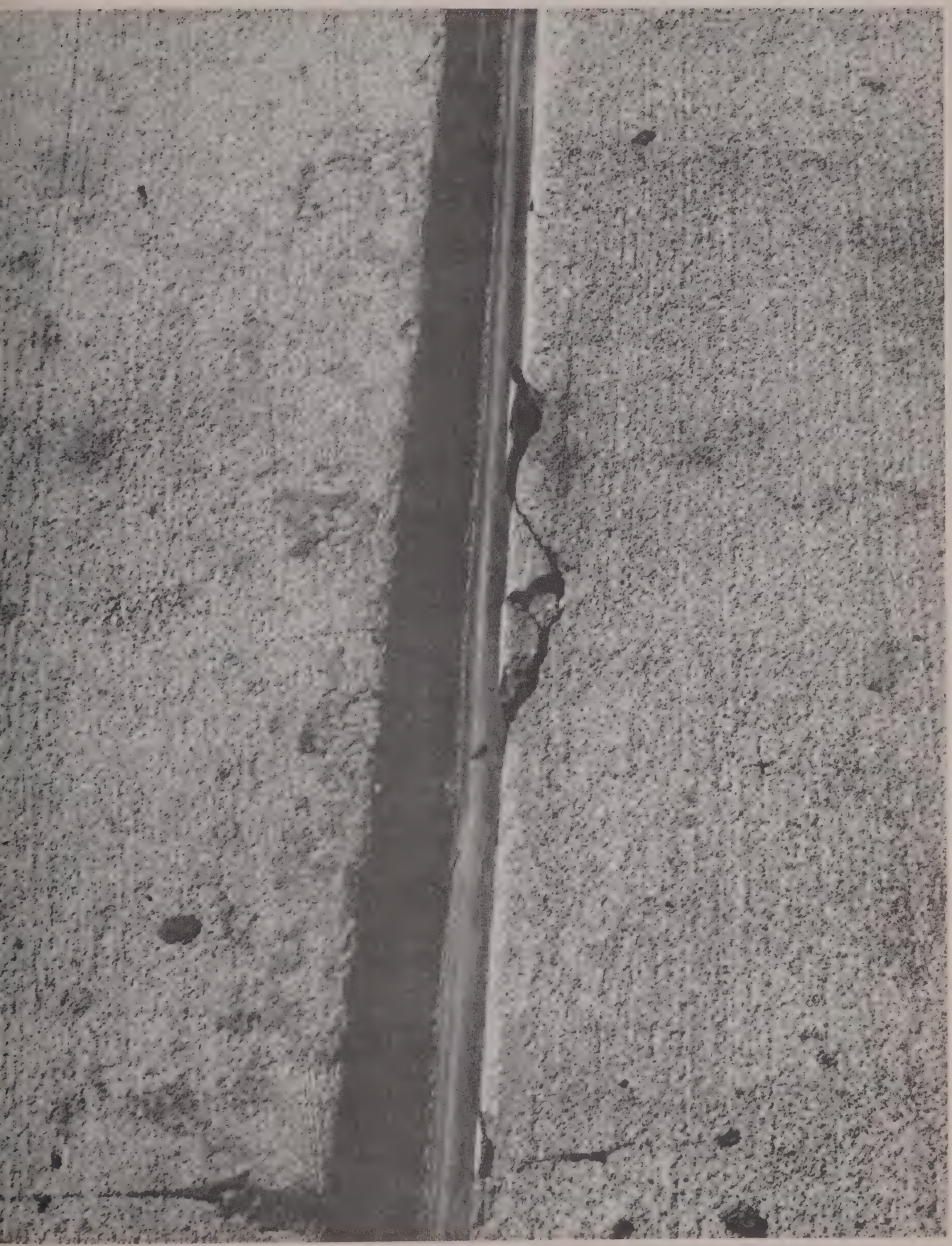


PHOTO NO. 14
This is how spalls are initiated.
Bridges No. 17a to f.

5. The bending of sealers at curbs is a persistent difficulty and very often a cause for inadequacy in performance. To understand this one has to realize that a short piece of sealer has to be bent almost 90 degrees, thus partially closing the voids inside the seal even before it is compressed into the joint. At the same time, it is a formidable physical operation to place the sealer in the joint while simultaneously bending it.

As a consequence an under-cut is necessary. As mentioned in Tables #9.1 to 9.8, this cut, often made with a penknife, is usually highly irregular; still, the placing is cumbersome and unsatisfactory (see photographs No. 15 and 16). No doubt, such an under-cut also weakens the sealer. In spite of the under-cut, the closing of voids does occur and, as recently observed, the result is the excessive compression of rubber at high temperatures, as revealed by length-wise cracks at bends.

PHOTO NO. 15
Sealers in sidewalk and curb.
Bridges No. 17a to f.

PHOTO NO. 16
Sealer in a curb. Note the staggering of curb-joint in reference to deck-joint.
Bridges No. 17a to f.

6. The sealers, when placed into joints, have at least two open ends exposed to the weather. To prevent damage to the sealers, attempts were made to seal the ends as follows:

   a. by a structural two-component liquid polymer sealer. When set, this material becomes hard and thus ineffectual.

   b. A flat piece of the rubber used in the sealers was glued with the adhesive to the open ends. It was found that these pieces had already separated when the sealer was installed.

7. Honey-combing, mentioned in Tables #9.1 to #9.8 and shown on Photographs No. 17 and 18 is apparently the result of wooden forms reused too often. Rainwater on the top of freshly poured concrete, on occasion did wash off the grout.

PHOTO NO. 17
Note the honey-combing and the grout marring.
Rt. 287, Sec. 6E.

PHOTO NO. 18
Note the honey-combing and the grout marring.
Rt. 287, Sec. 6E.

8. No seats for sealers were provided in the sidewalks or curbs. This detail has been extensively discussed in prior chapters.

9. Bending up of deck-joint sealers into sidewalk joints, by placing them through the curb-joints, is cumbersome, to say the least. On one occasion, skewed joints were constructed in such a manner that the curbs were overhanging the deck-joints (see Photographs No. 19 and 20). The sealer had to be forced under the curb by means of a wire wrapped around the sealer end. In another case, the sealer was placed into the deck-joints out to out (see Photograph No. 21) and a protective cork strip was used in the vicinity of the sidewalks to prevent grout from accumulating on the top of the deck sealers. Again, on another bridge, sealers in the deck were stopped only a few inches beyond the curb bottom line.

10. Whenever a change in horizontal skew angle of a joint occurs, the sealer fits rather poorly into the joint, apparently not being able to conform to the sharp angular changes (see Photograph No. 22).

11. Opening of the joints due to initial setting of concrete was observed.

The sealers' physical dimensions could not be thoroughly checked in the field. But it is felt that the data available (see Tables #9.1 to #9.8), when taken in the light of previous discussions elsewhere in this report, indicate a need for improvement in their manufacture.

The data discussed above make us conclude that improvements are needed in design, and, most of all, in the methods and performance of construction.

PHOTO NO. 19
Note the curb overhand.
Bridges No. 17a to f.

PHOTO NO. 20
Close-up of curb overhang.
Bridges No. 17a to f.

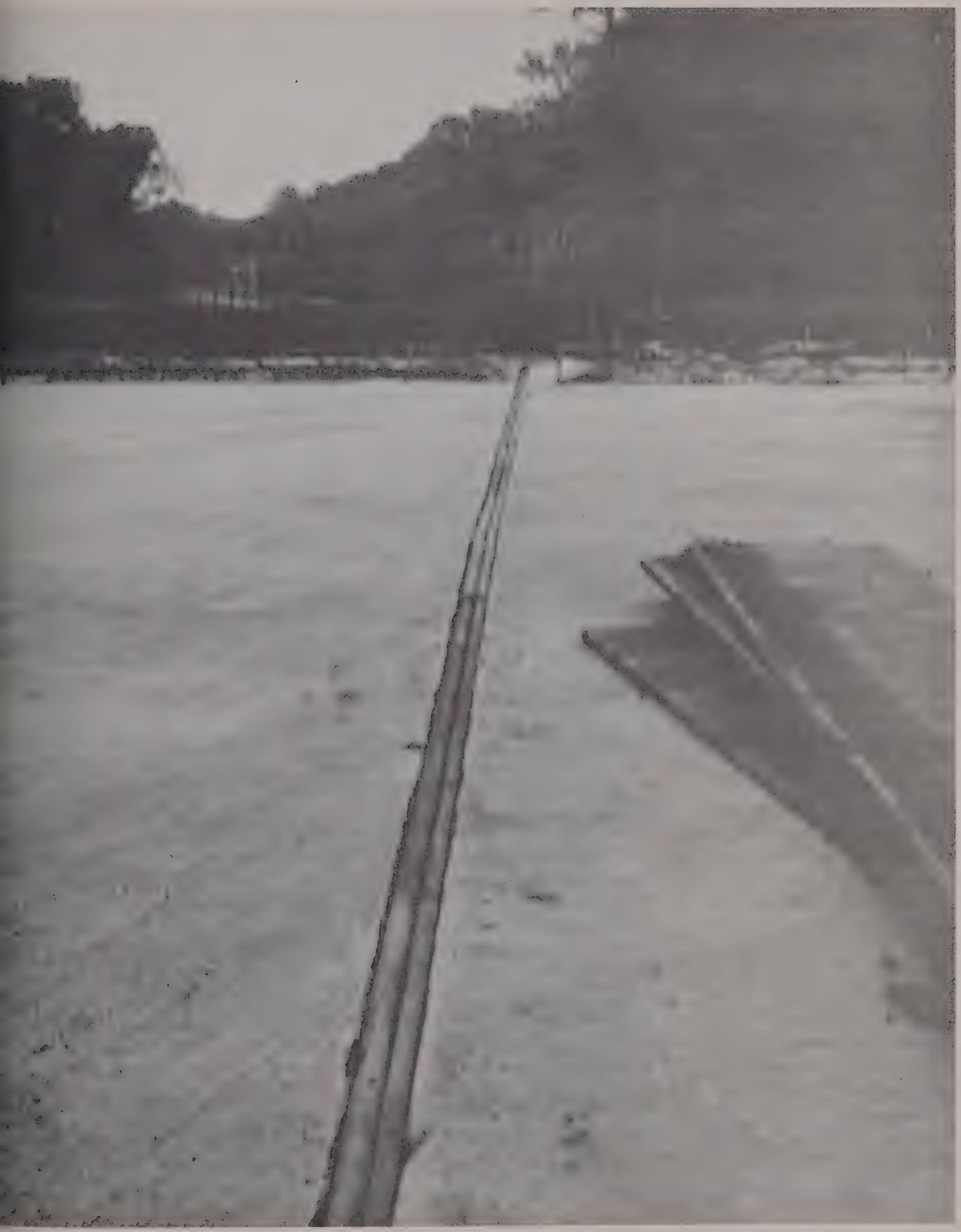


PHOTO NO. 21
Full length of deck joint is being sealed.

PHOTO NO. 22
Placing of sealer into a joint with changing horizontal skew angle.

General Further Observations

The attached graphs No. 1 to 12 exemplify two major groups of bridges: one is skewed, the other is perpendicular to the span. The basic design principles, as related to movements of simple span bridges, were already outlined in a brief discussion and illustrated by Figures #6 & #7 elsewhere in this report. The two (2) subject bridges are:

Table #10

Initial Bridge Data

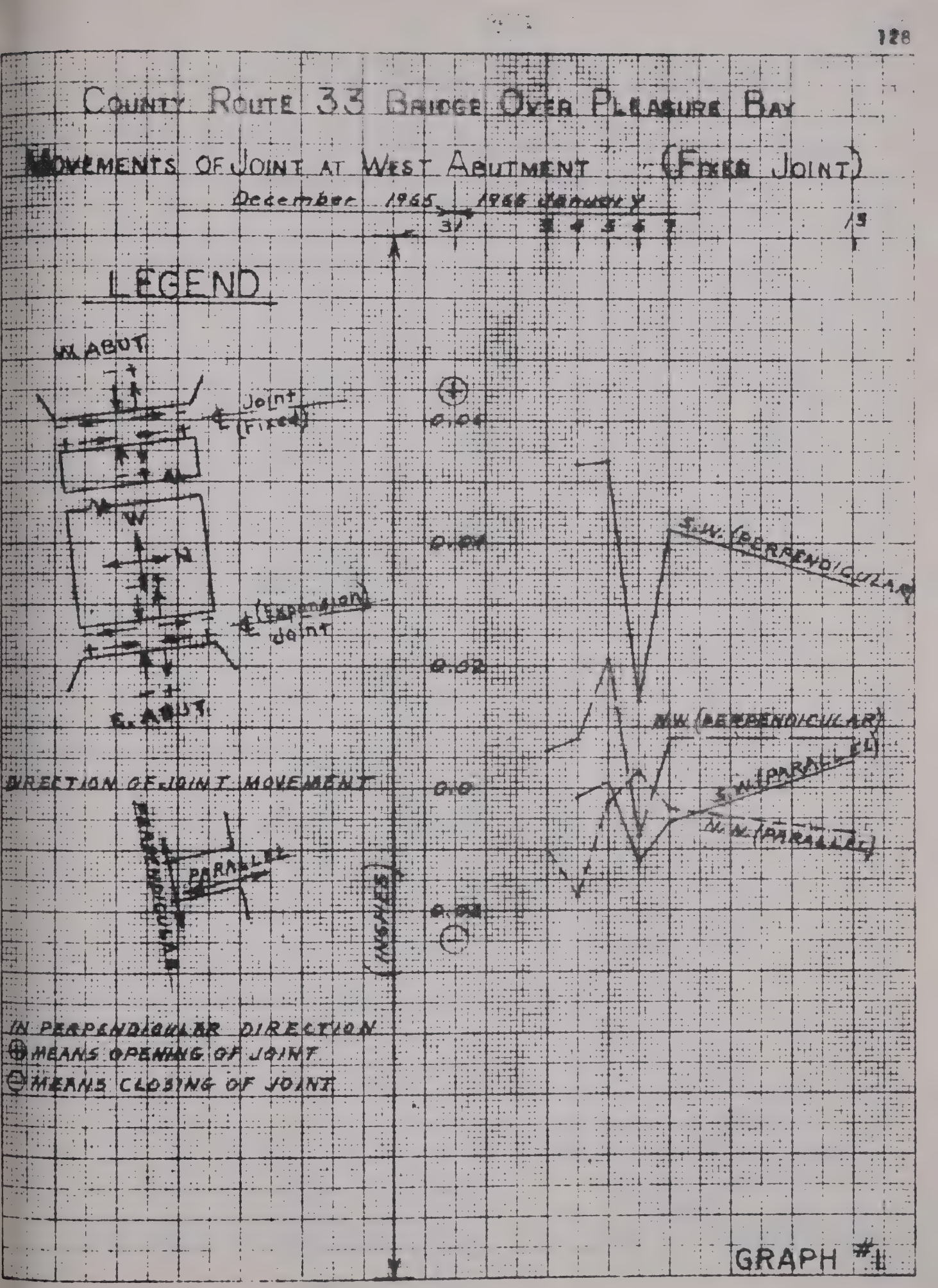
ge & tion	Initial Span Length		Skew Angle of Joints			
	E. Side	W. Side	#1 S-E	#2 N-E	#1 S-W	#2 N-E
287 11A &	100.5783	99.7504	32°41'57"	32°44'56"	31°47'16"	31°50'14"
	S. Side	N. Side	S-W Abut.	N-W Abut.	S-E Abut.	N-E Abut.
33 sure	At W. Abutment 80.1265	80.1262	90°	90°	90°	90°
	At E. Abutment 82.0307	82.0033				

Graphs No. 5 through 12, present data on average seasonal values of: bridge deck-end movements, temperatures, and efficiency coefficients. Graphs No. 1 through 4 are samples to illustrate actual daily changes in measured movements and air temperatures; as well as the corresponding computed values of increments in concrete temperatures (theoretical variations) and degrees of sealer compression (sealer efficiency - X, Y and Z in %).

County Route 33 Bridge Over Pleasure Bay

Movements of Joint at West Abutment (Fixed Joint)

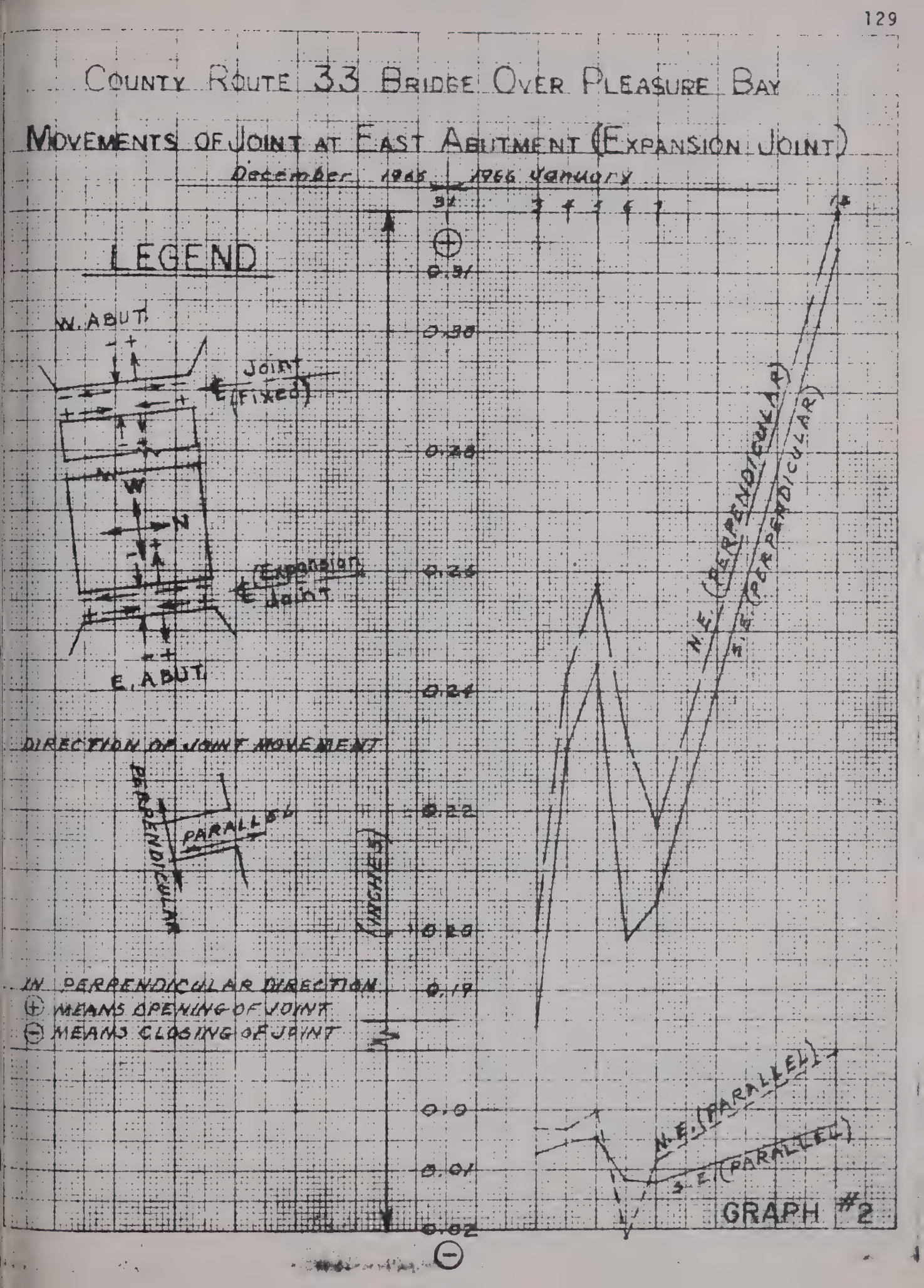
December 1965 — 1966 January



GRAPH #1

County Route 33 Bridge Over Pleasure Bay

Movements of Joint at East Abutment (Expansion Joint)



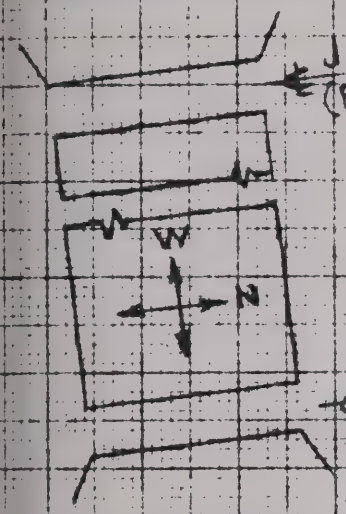
County Route 33 Bridge Over Pleasure Bay

Air-Concrete Temperature Relationship

December 1965 | 1966 January

31 3 4 5 6 7 13

LEGEND



W. ABUT (CONC.) = daily theoretical variation of conc. temp. at W. ABUT. joint

E. ABUT. (CONC.) = daily theoretical variation of conc. temp. at E. ABUT. joint.

AIR = measured air temp.

(DEGREES FAHRENHEIT)

20° 25° 30° 35° 40° 45° 65° 70° 75°

E. ABUT. (CONC.)

AIR

W. ABUT. (CONC.)

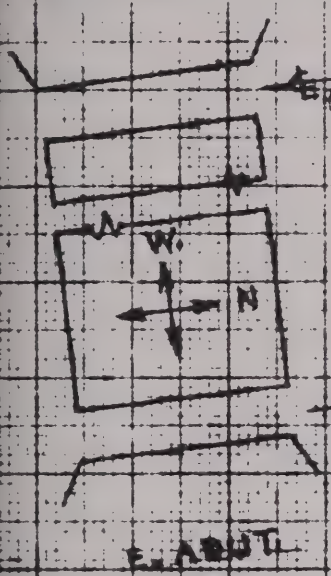
GRAPH #3

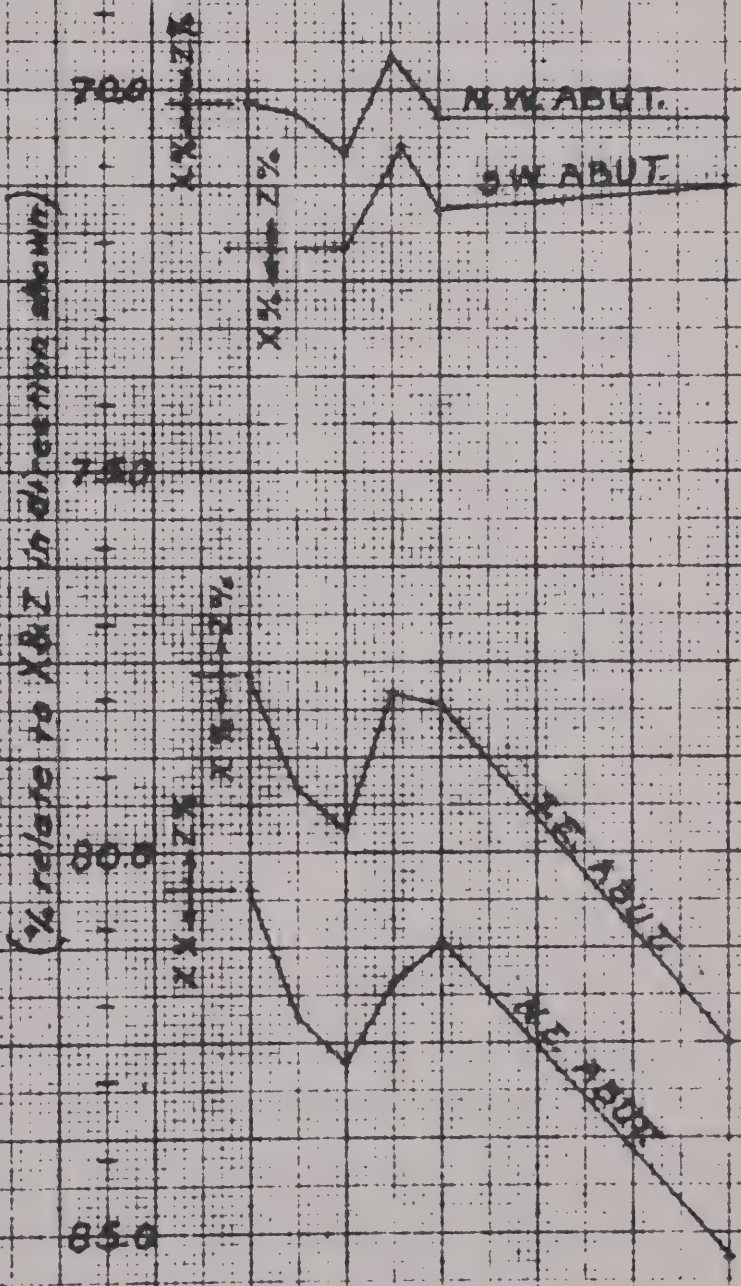
County Route 33 Bridge Over Pleasure Bay

Study of Sealer Efficiency

December 1965 | 1966 January

LEGEND





GRAPH #4

The magnitude of the daily movements and the perpetuity of bridge motion are apparent from these graphs (No. 1 to 4). The extent of these movements, combined with the sporadic character of our field measurements, made it necessary for us to revert to the arithmetic averages of these data in plotting them on a yearly basis. Otherwise, the results would, in some instances, indicate erroneous trends. Here, one should be reminded that no effective concrete temperature could be calculated, but only the incremental changes in it. The initial concrete temperatures therefore were arbitrarily assumed as being equal to the slab temperatures theoretically calculated on the basis of the thermal effects study, as already discussed elsewhere in this report, and as shown on graphs # 11 and #7.

Of the two (2) bridges presented, only bridge #21 was completely covered by plug installations. On the Pleasure Bay bridge, the plugs were placed only at abutment joints, where the sealers are located. The joints at the piers are not sealed. To achieve a proper relationship between the deck-end movements and the concrete temperatures, the calculations used to determine them must reflect the total sum of movements of both ends of the span. Regrettably, this could not quite be achieved in the case of Pleasure Bay Bridge.

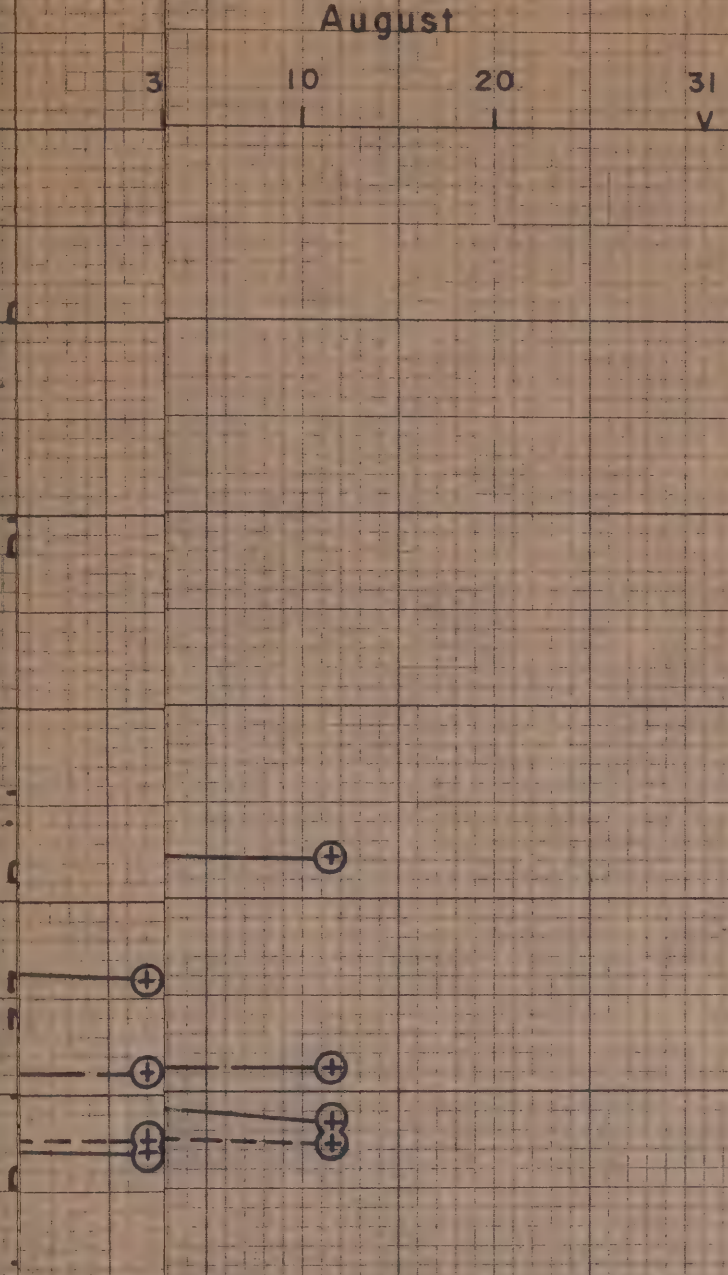
Another important relationship is that between the temperatures of air and of concrete. This reflects on the comparison between the theoretically calculated and the

actual deck-end movements. Although the air temperatures were measured mostly around noon and our computed concrete temperature values are influenced by the factors heretofore discussed, the general agreement is quite apparent, as manifested in the attached graphs. Of course, one should not be misled into an attempt to evaluate the above in any absolute manner.

These studies lead to FURTHER CONCLUSIONS common, as it seems, to all bridges: small but continuous movements occur at fixed deck-ends; rather insignificant variations take place in the compression of sealers utilized in so-called "fixed joints", i.e. joints where both deck-ends forming the joint are "fixed"; excessive relaxation of seals in expansion joints can be observed whenever these were installed at a higher percentage of compression, or so-called degree of efficiency, than that suggested in this report (Y=55% to 60%). In fact, should they have been installed as proposed, the limits of their efficiency would fall quite closely within the boundaries offered (Z = 40%± to X = 70%± to 80%±); this substantiates the recommendations made elsewhere in this report.

Graphs Nos. 9 to 12 illustrate the "skewed" group of bridges, while the "perpendicular to the span" group is represented by graphs #5 to #8. The principal difference in their behavior is indicated on graphs #9, 10, 5 and 6. In the latter group (graphs Nos. 5 to 8), throughout the yearly cycle, the movements parallel to the joint are quite small

and the perpendicular movements do follow the thermal changes. A comparison of the movements at each end of a given joint shows close agreement. All this stands to reason. The movements are thermal as expected and, therefore, due to expansion and contraction of material of uniform width and length, they should be for all practical purposes the same; and for the small expansion or contraction width, they should be insignificant.



GRAPH No. 5

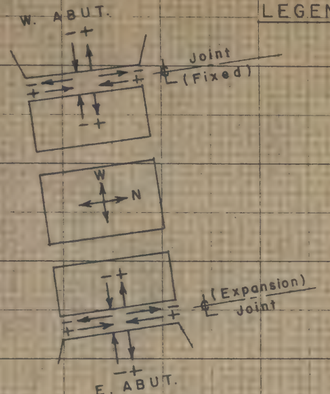
County Route 33
Bridge over Pleasure Bay

County Route 33 Bridge over Pleasure Bay
Movements of Joint at West Abutment (Fixed Joint)

July | August | September | October | November | December | January | February

1 10 20 31 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31 10 20

1965 | 1966



LEGEND

DIRECTION OF JOINT MOVEMENT

IN PERPENDICULAR DIRECTION
⊕ MEANS OPENING OF JOINT
⊖ MEANS CLOSING OF JOINT

The lines represent average seasonal bridge and movements.

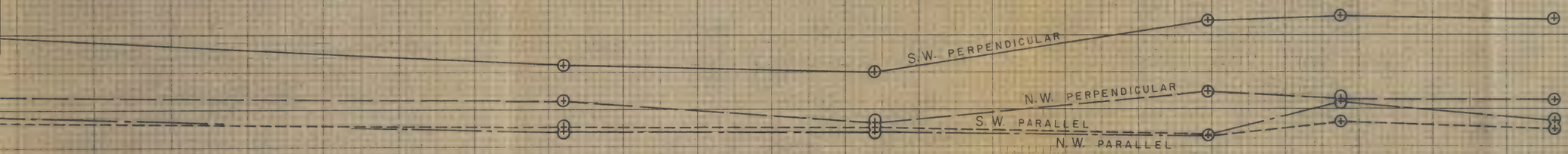
(Inches)

⊕ 0.08 0.04 0.00 0.04 0.08 ⊖

S.W. PERPENDICULAR
N.W. PERPENDICULAR
S.W. PARALLEL
N.W. PARALLEL

nuary | February | March | April | May | June | July | August

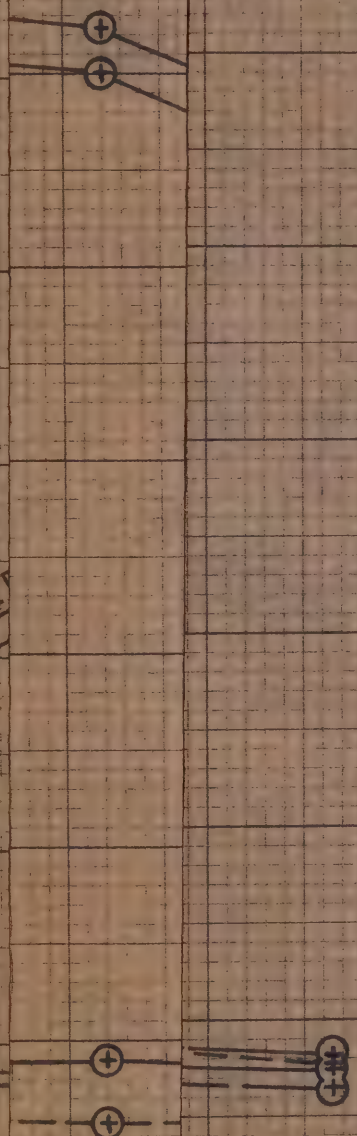
20 31 10 20 28 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31



GRAPH No. 5

August

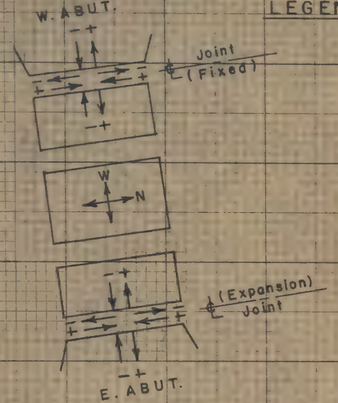
31 10 20 31



GRAPH No. 6

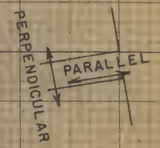
County Route 33
Bridge over Pleasure Bay

County Route 33 Bridge over Pleasure Bay
Movements of Joint at East Abutment (Expansion Joint)



LEGEND

DIRECTION OF JOINT MOVEMENT



IN PERPENDICULAR DIRECTION
⊕ MEANS OPENING OF JOINT
⊖ MEANS CLOSING OF JOINT

The lines represent average seasonal bridge end movements.

July | August | September | October | November | December | January | February

1965 | 1966

(Inches)

⊕ 0.24 | 0.20 | 0.16 | 0.12 | 0.08 | 0.04 | 0.00 | 0.04 ⊖

N.E. PERPENDICULAR

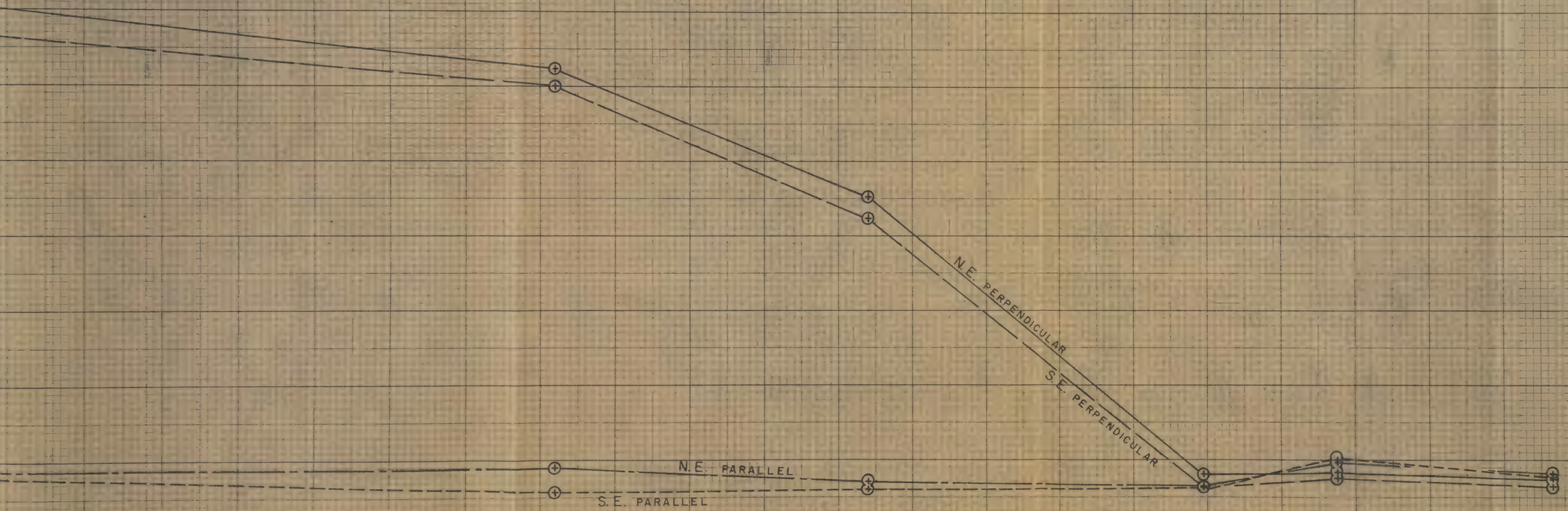
S.E. PERPENDICULAR

N.E. PARALLEL

S.E. PARALLEL

uary | February | March | April | May | June | July | August

20 31 10 20 28 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31



GRAPH No. 6

August

10 20 31

Ass

GRAPH No. 7

County Route 33
Bridge over Pleasure Bay

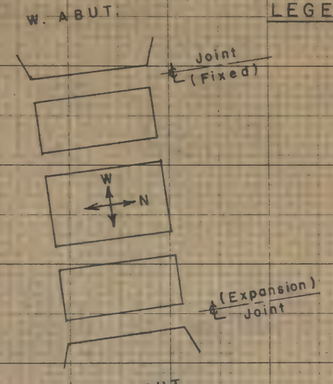
County Route 33 Bridge over Pleasure Bay
Air – Concrete Temperature Relationship

(Degrees Fahrenheit)

July | August | September | October | November | December | January | Februar

1 10 20 31 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31 10 2

1965 | 1966



LEGEND

The lines represent average seasonal temp. variations.

W. ABUT. (CONC.) = average theoretical change of conc. temp. at W. ABUT. joint.
E. ABUT. (CONC.) = average theoretical change of conc. temp. at E. ABUT. joint.
AIR = measured air temp.

30° 40° 50° 60° 70° 80°

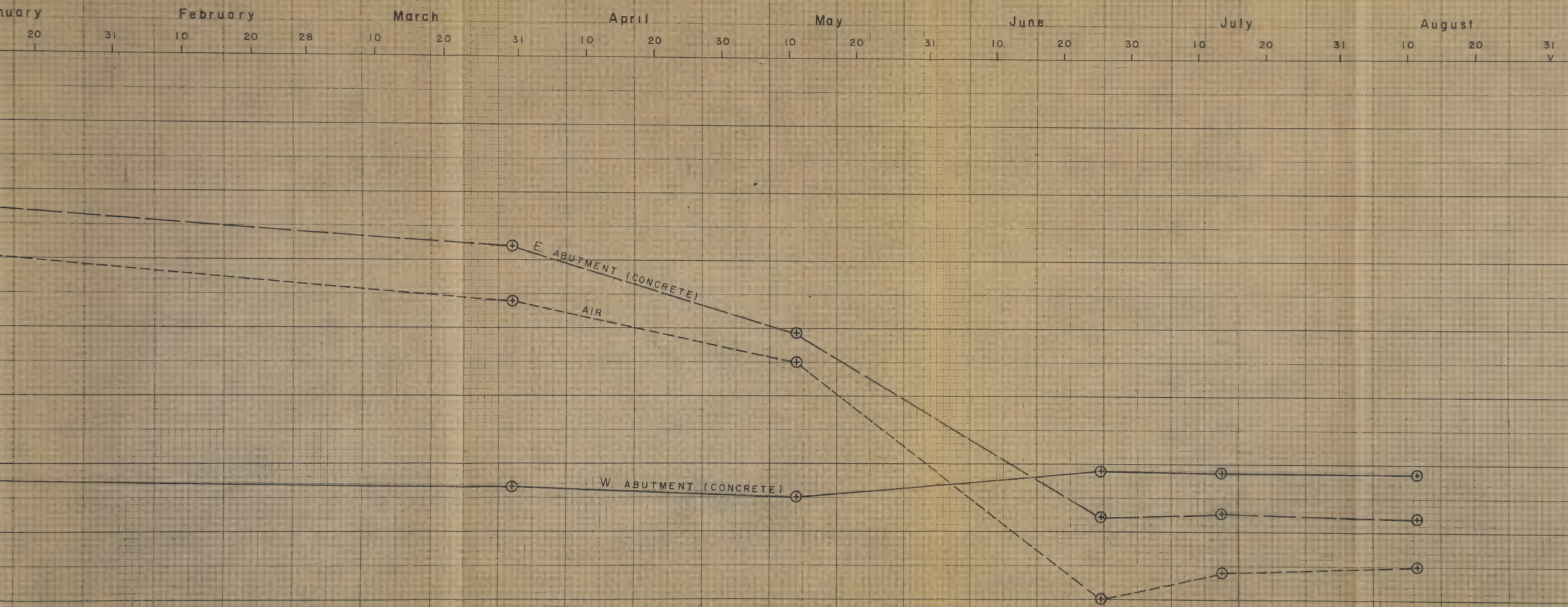
Air Temp.

Assumed Conc. Temp.

W. ABUTMENT (CONCRETE)

E. ABUTMENT (CONCRETE)

AIR


uary
February
March
April
May
June
July
August
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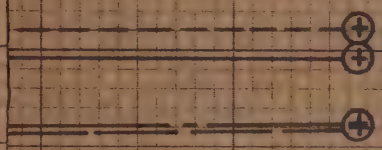
31
10
20
28
10
20
31
10
20
30
10
20
31
10
20
30
10
20
31
10
20
31
E. ABUTMENT (CONCRETE)
AIR
W. ABUTMENT (CONCRETE)

GRAPH No. 7

August

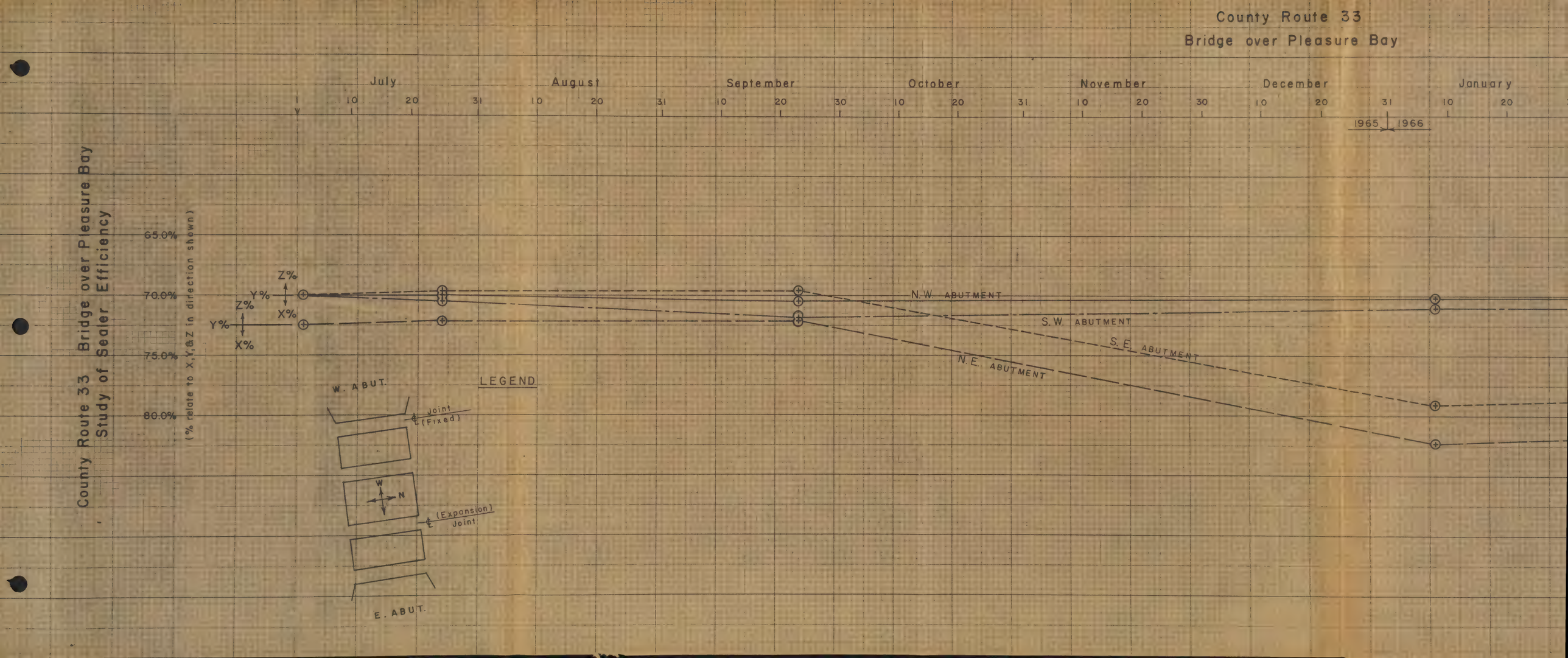
31 10 20 31



County Route 33 Bridge over Pleasure Bay

GRAPH No. 8

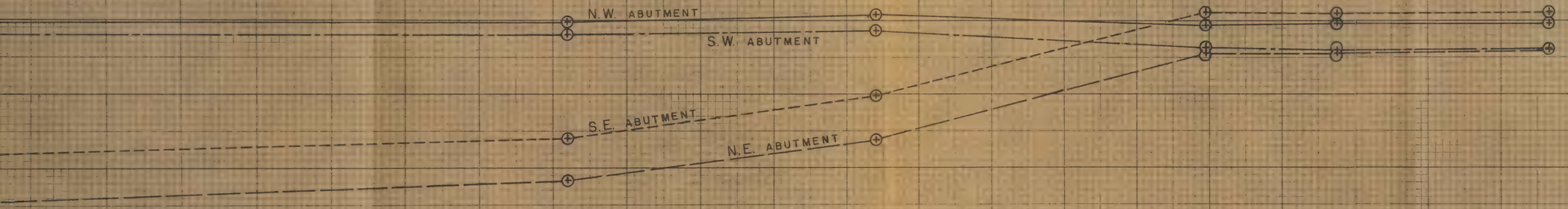
County Route 33
Bridge over Pleasure Bay



County Route 33 Bridge over Pleasure Bay
Study of Sealer Efficiency

anuary | February | March | April | May | June | July | August

20 31 10 20 28 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31



GRAPH No. 8

Now, in the "skewed" group (graphs Nos. 9 to 12) the movements, one could say, are erratic and, therefore, deeper analyses are necessary.

As hitherto already shown, a deck is guided to move parallel to joints and supporting beams. These are movements "$\Delta X = \Delta X_T + \Delta X_p$" and "$\Delta V$" as demonstrated in figure #12. In the "perpendicular to the span" bridges "$\Delta X = \Delta X_p$" and "$\Delta V = \Delta Y$" are normally all the motions to be expected. But, in the "skewed" bridges the "ΔY" and "ΔX_T", being vector components of "ΔV", are functions of the skew, while "ΔX_p" is as before, a function of the expansion or contraction width of a deck slab.

"ΔX_T" is movement parallel to the joint, as is "ΔX_p". "ΔX_T" can be calculated, as opposed to being measured and is therefore named "theoretical ΔX movement."

What happens is that, as far as the joints and sealers are concerned, each point along the deck sides of a joint, can be represented by two components of travel, namely perpendicular "ΔY" and parallel "$\Delta X = \Delta X_T + \Delta X_p$" to a joint. The perpendicular component compresses the sealer, and the parallel component causes a drag along a sealer's vertical sides which can possibly cause either migration or strain, either constant or time dependent. This strain will induce longitudinal compression or elongation and/or shear

stresses. Since no migration was yet observed, as already mentioned elsewhere in this report, the case indicates likely strain conditions.

As is also apparent from figure #12 the "ΔX_T" component may be either opposite to or in the same direction with, "ΔX_p" in diagonally opposite corners of the same deck. Depending on the skew angle, the span, and the width of a bridge deck "$\Delta X_T \lesseqgtr \Delta X_p$". When the span and the skew angle are large and the width is relatively small, "$\Delta X_T > \Delta X_p$", as is demonstrated in graphs #9 and 10.

Further, as a consequence of the above, the total shifting parallel with the joints at the opposite ends of a span, is either in clockwise or counterclockwise direction, possibly causing a slight rotation of the bridge-deck slab. The direction and the magnitude of such movements are functions of the expansion or contraction cycle and of the degree of fixity at the alignment bearings. This rotation phenomenon appears as being reflected in the differential closure or opening of the opposite ends of a joint.

LEGEND:

ΔV = Parallel To The Beams Movements Of Deck

ΔX_P = Parallel To The Joint Movements Of Deck

ΔY = Perpendicular To The Joint Movements Of Deck

ΔX_T = Parallel To The Joint Component Of "ΔV"

R_R And R_L = Right Or Left Bridge Deck Rotation

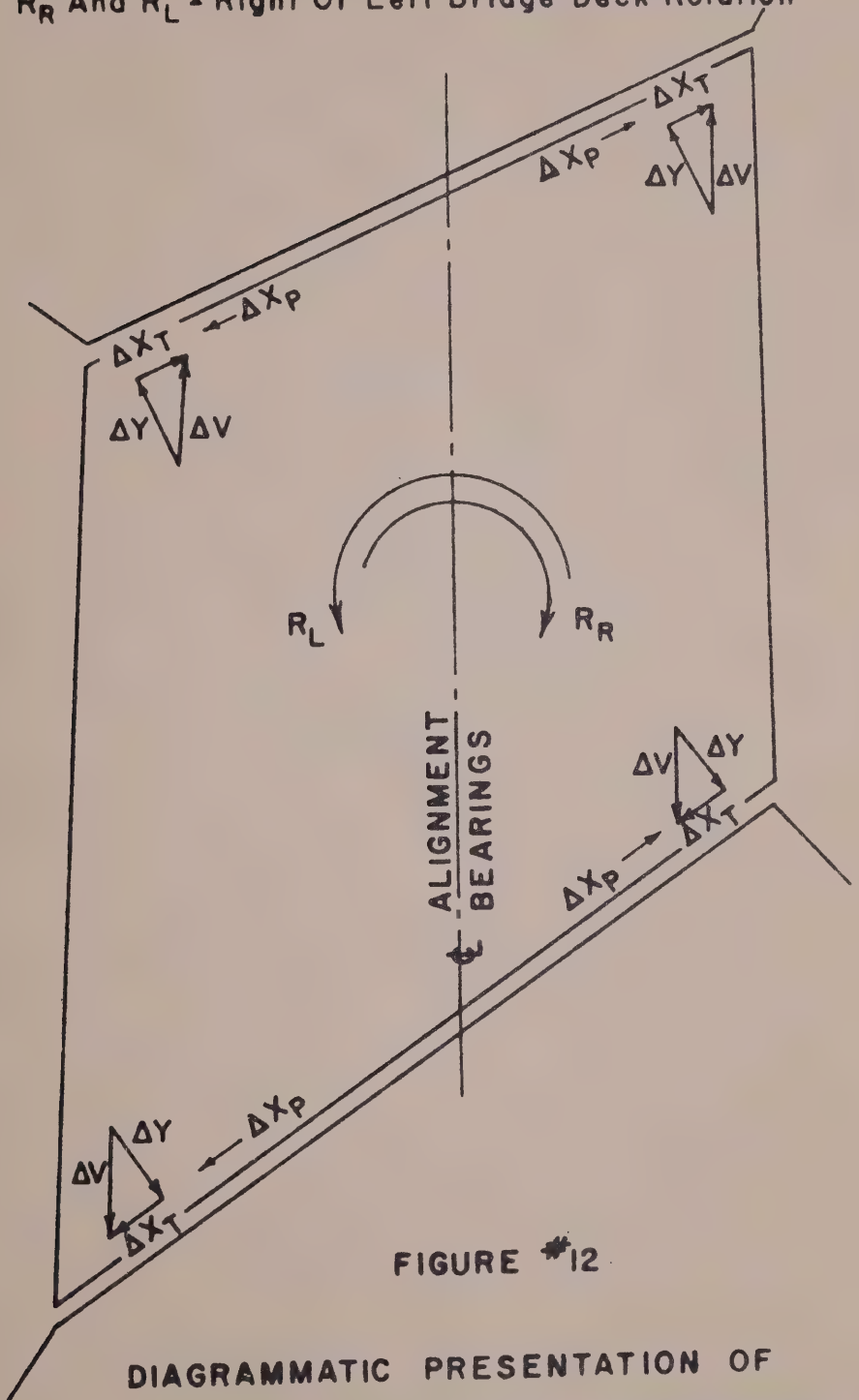
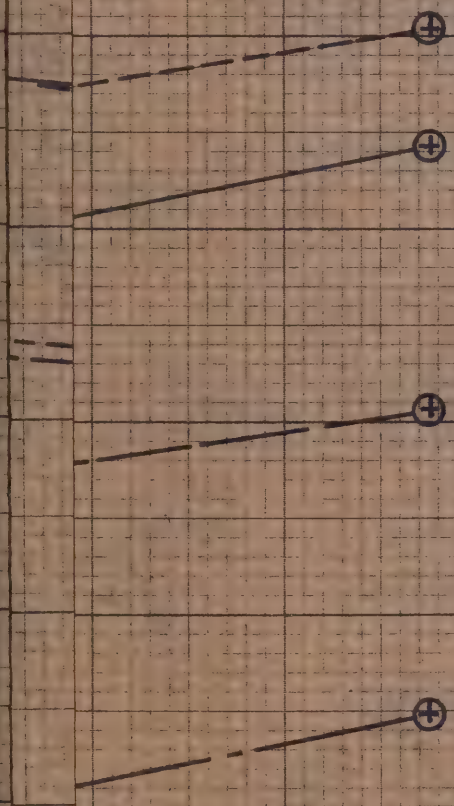


FIGURE #12

DIAGRAMMATIC PRESENTATION OF "SKEWED" BRIDGE DECK MOVEMENTS

August

28 31 10 20 31



GRAPH No. 9

Route 287
Sec. 11A & 12C
Bridge No. 21

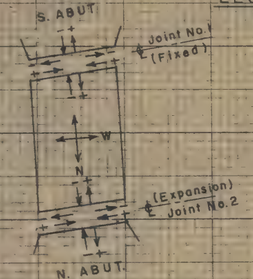
Route 287 Sec. 11A & 12C Bridge No. 21
Movements of Joint No. 1 (Fixed Joint)

June | July | August | September | October | November | December | January | February

10 20 30 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31 10 20

1965 | 1966

LEGEND



DIRECTION OF JOINT MOVEMENT

IN PERPENDICULAR DIRECTION
⊕ MEANS OPENING OF JOINT
⊖ MEANS CLOSING OF JOINT

The lines represent average seasonal bridge end movements.

(Inches)

⊕ 0.08
0.04
0.00
0.04
⊖ 0.08

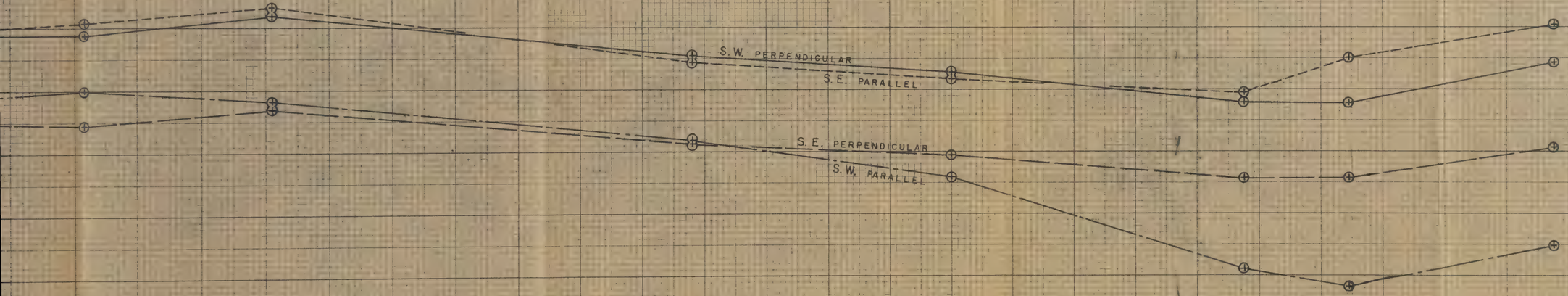
S.W. PERPENDICULAR
S.E. PARALLEL
S.E. PERPENDICULAR
S.W. PARALLEL

287
8 12C
No. 21

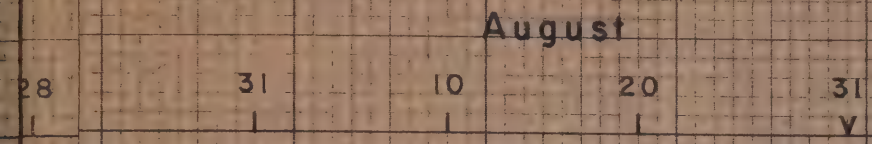
December | January | February | March | April | May | June | July | August

10 20 31 10 20 31 10 20 28 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31

1965 1966



GRAPH No. 9



GRAPH No. 10

Route 287
Sec. 11A & 12C
Bridge No. 21

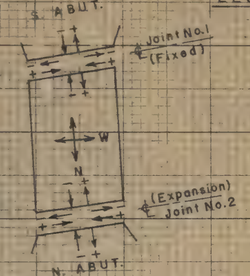
Route 287 Sec. 11A & 12C Bridge No. 21
Movements of Joint No. 2 (Expansion Joint)
(Inches)

June | July | August | September | October | November | December | January | February

1 10 20 30 10 20 31 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31 10 20

1965 | 1966

⊕ 0.16 0.12 0.08 0.04 0.0 0.04 0.08 0.12 ⊖



LEGEND

DIRECTION OF JOINT MOVEMENT

IN PERPENDICULAR DIRECTION
⊕ MEANS OPENING OF JOINT
⊖ MEANS CLOSING OF JOINT

The lines represent average seasonal bridge end movements.

N.W. PARALLEL

N.W. PERPENDICULAR

N.E. PERPENDICULAR

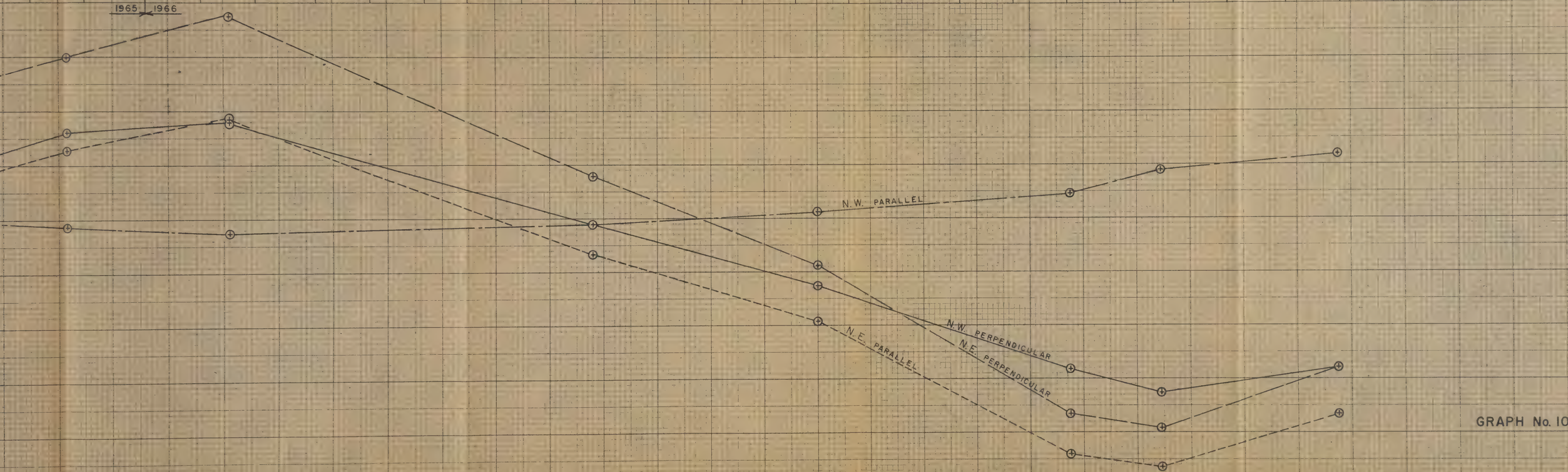
N.E. PARALLEL

87
12C
o. 21

December | January | February | March | April | May | June | July | August

10 20 31 10 20 31 10 20 28 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31

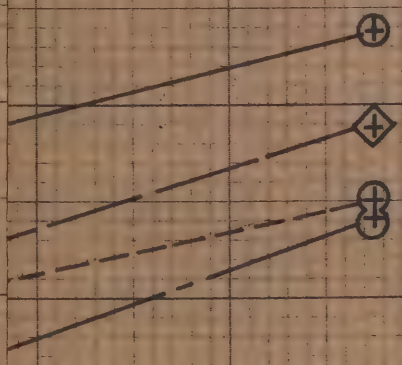
1965 1966



GRAPH No. 10

August

31 10 20 31



GRAPH No. 11

Route 287
Sec. 11A & 12C
Bridge No. 21

Route 287 Sec. 11A & 12C Bridge No. 21
Air-Concrete Temperature Relationship

(Degrees Fahrenheit)

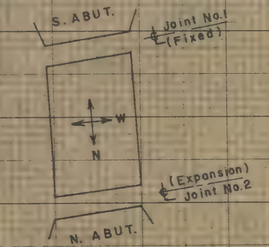
June | July | August | September | October | November | December | January | February

10 20 30 10 20 31 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31 10 20

1965 | 1966

30° 40° 50° 60° 70° 80° 90°

LEGEND



The lines represent average seasonal temp. variations.

N.W. – S.W. = theoretical variations of conc. temp. on the west side of BRIDGE DECK.
N.E. – S.E. = theoretical variations of conc. temp. on the east side of BRIDGE DECK.
CONC. AV. = averaged theoretical variations of conc. temp. (AV. of N.W. – S.W. and N.E. – S.E. LINES.)
AIR = measured air temp.

Air Temp.
Assumed Conc. Temp.

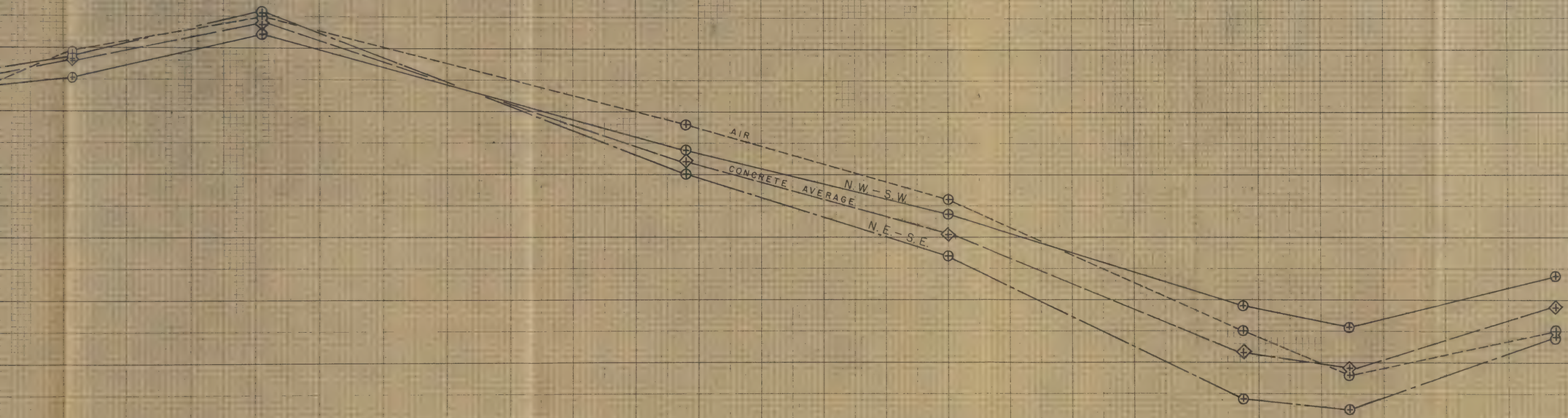
N.W. – S.W.
CONCRETE AVERAGE
AIR
N.E. – S.E.

37
12C
o. 21

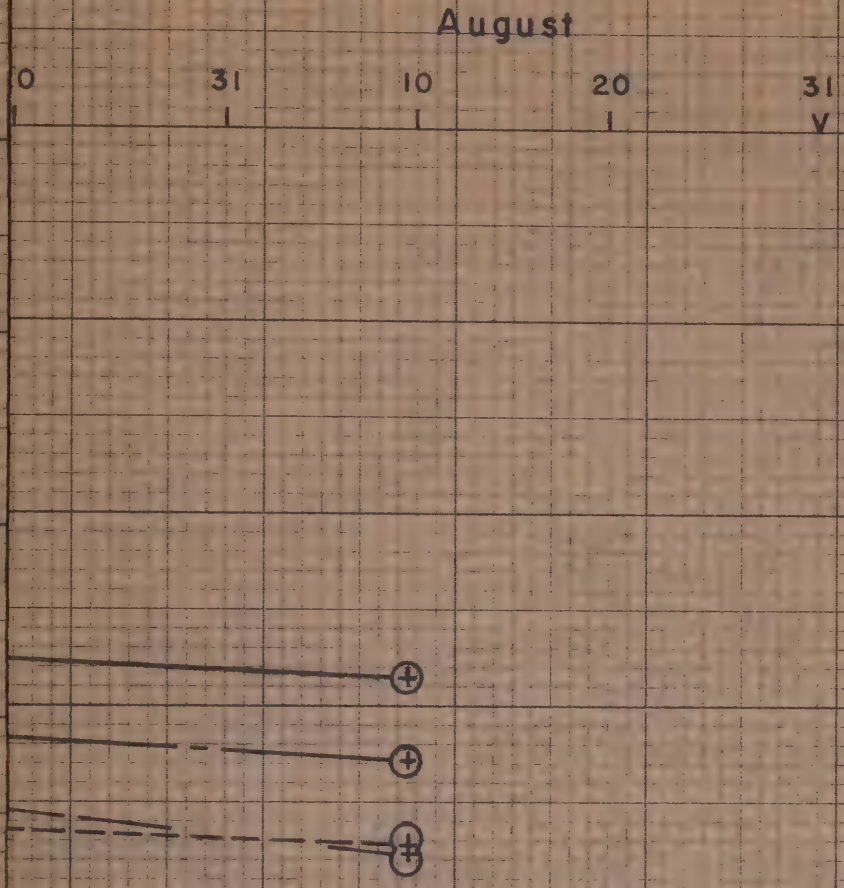
December | January | February | March | April | May | June | July | August

10 20 31 10 20 31 10 20 28 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31

1965 | 1966



GRAPH No. 11



GRAPH No. 12

Route 287
Sec. 11A & 12C
Bridge No. 21

Route 287 Sec. 11A & 12C Bridge No. 21
Study of Sealer Efficiency

(% relate to X, Y, & Z in direction shown)

June | July | August | September | October | November | December | January | February

1965 | 1966

60.0%
65.0%
70.0%
75.0%
80.0%

JOINT #1 S.E.
JOINT #1 S.W.
JOINT #2 N.E.
JOINT #2 N.W.

Z%
Y%
X%

LEGEND

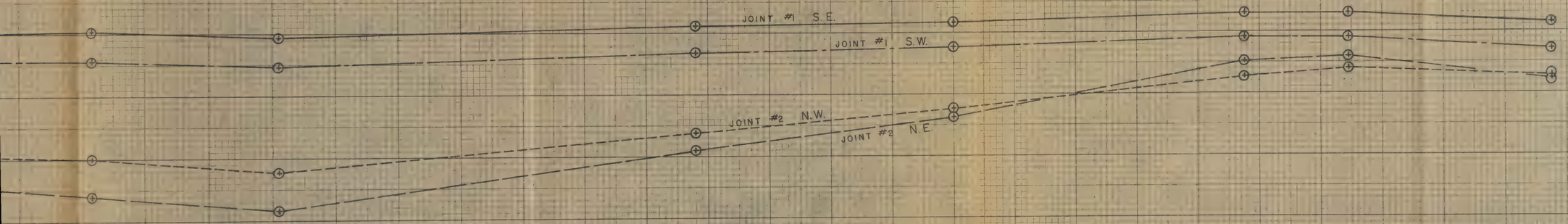
S. ABUT.
℄ Joint No.1 (Fixed)
W
N
℄ (Expansion) Joint No.2
N. ABUT.

287
8 12C
No. 21

December | January | February | March | April | May | June | July | August

10 20 31 10 20 31 10 20 28 10 20 31 10 20 30 10 20 31 10 20 30 10 20 31 10 20 31

1965 | 1966



GRAPH No. 12

When studied in the light of the above discussion, Graphs #9 and #10 become deducible, less entangled, and erratic only in appearance.

As already said, Table # 4 is simply a summary of what is considered important information from graphs for all the observed bridges. It shows, listed by bridges and dates, the data relative to the "sealers' efficiency", and joint movements and widths; all in relation to the measured air temperatures.

BRIDGE AND JT. NOS.	DATE: INSTALL. MAX. & MIN.	DEGREE OF EFFICIENCY @ INSTALL Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	END MOV. MAX. MIN. PERP.	PARA.	JT. WIDTH "W_j" INSTALL. MAX. MIN.
15a. skew								
N. Abut.								
NE	10/14/65	65.9			64			1.81
Exp.	1/14-19/66		70.4		34	+0.125		1.94
	7/18-19/66			59.9	90	-0.171		1.64
	1/14-19/66				34		+0.132	
	7/18-19/66				90		-0.243	
N. Abut.								
NW	10/14/65	61.3			64			1.69
Exp.	1/14-19/66		65.3		34	+0.109		1.79
	7/18-19/66			55.0	90	-0.178		1.51
	7/18-19/66				90		+0.198	
	1/14-19/66				34		-0.051	
S. Abut.								
SE	10/14/65	61.3			64			1.68
Exp.	12/20-23/65		61.4		37	+0.003		1.69
	7/18-19/66			52.6	90	-0.236		1.45
	7/18-19/66				90		+0.383	
	--				--		--	
S. Abut.								
SW	10/14/65	63.6			64			1.75
Exp.	12/20-23/65		66.3		37	+0.079		1.83
	7/18-19/66			56.3	90	-0.204		1.55
	12/20-23/65				37		+0.187	
	7/18-19/66				90		-0.305	
15c. skew								
N. Abut.								
NE	10/14/65	61.3			64			1.69
Exp.	12/20-23/65		63.1		37	+0.049		1.73
	6/23-24/66			53.0	86	-0.230		1.46
	12/20-23/65				37		+0.039	
	7/18-19/66				90		-0.152	

TABLE NO. 4.1

BRIDGE AND JT. NOS.	DATE: INSTALL. MAX. & MIN.	DEGREE OF EFFICIENCY @ INSTALL. Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	END MOV. MAX. MIN. PERP.	PARA.	JT. WIDTH "Wj" INSTALL. MAX. MIN.
15c. (cont'd)								
N. Abut.								
NW	10/14/65	66.0			64			1.82
Exp.	12/20-23/65		68.5		37	+0.075		1.89
	7/18-19/66			56.8	90	-0.252		1.56
	7/18-19/66				90		+0.111	
	1/14-19/66				33		-0.008	
3a. skew								
1SE	6/16/65	65.8			62			1.65
Fix.	1/10-20/66		65.3		35	-0.012		1.63
	9/22/65			62.8	89	-0.075		1.57
	1/10-20/66				35		+0.054	
	9/22/65				89		-0.054	
1SW	6/16/65	65.8			62			1.65
Fix.	1/10-20/66		67.7		35	+0.048		1.69
	9/22/65			65.0	89	-0.019		1.63
	12/13-20/66				41		+0.000	
	7/7-8/66				92		-0.128	
2NE	6/16/65	72.5			62			1.81
Exp.	1/10-20/66		79.2		35	+0.170		1.98
	7/7-8/66			67.0	92	-0.137		1.68
	1/10-20/66				35		+0.094	
	7/7-8/66				92		-0.166	
2NW	6/16/65	72.5			62			1.81
Exp.	1/10-20/66		76.1		35	+0.092		1.91
	7/7-8/66			68.0	92	-0.111		1.70
	8/9-10/66				85		+0.068	
	1/10-20/66				35		+0.093	

TABLE NO. 4.2

BRIDGE AND JT. NOS.	DATE: INSTALL. MAX. & MIN.	DEGREE OF EFFICIENCY @ INSTALL. Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	END MOV. MAX. MIN. PERP.	PARA.	JT. WIDTH "W_j" INSTALL. MAX. MIN.
9b. skew								
	While the data on this bridge are of some technical interest, their lack of precision makes it preferable not to include them.							
10b.								
2NE	6/24/65	68.7			80			1.72
Exp.	1/10-12/66		87.6		27	+0.475		2.19
	7/7-8/66			73.9	81	+0.129		1.85
	11/30/65-12/16/66				42		+0.002	
	--				--	--		
	--				--	--		
	7/7-8/66				81		-0.008	
2NW	6/24/65	62.4			80			1.72
Exp.	1/10-12/66		77.1		27	+0.450		2.16
	7/7-8/66			64.3	81	+0.102		1.82
	7/20-30/65				81		-0.006	
	6/20-21/66				79		-0.026	
3E	6/23/65	66.9			98			1.67
Exp.	--	--			--			--
	1/10-12/66		67.6		27	+0.019		1.69
	7/7-8/66			58.1	81	-0.127		1.46
	11/30-12/16/65				42		+0.003	
	8/9-10/66				79		+0.003	
3W	6/23/65	66.8			98			1.67
Exp.	1/10-12/66		67.2		27	+0.004		1.68
	7/7-8/66			57.1	81	-0.244		1.43
	7/20-30/65				81		+0.001	
	5/2-6/66				56		-0.021	

TABLE NO. 4.3

BRIDGE AND JT. NOS.	INSTALL. MAX. & MIN. DATE	DEGREE OF EFFICIENCY @ INSTALL. Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	END MOV. MAX. MIN. PERP.	PARA.	INSTALL. MAX. MIN.
10b. (cont'd)								
4SE	6/23/65	65.1			98			1.79
Exp.	--	--			--			--
	1/10-12/66		70.3		27	+0.142		1.93
	7/26-30/65			63.7	92	-0.038		1.75
	7/26/65				92		+0.001	
	1/10-12/66				27		-0.019	
4SW	6/23/65	69.0			98			1.72
Exp.	1/10-12/66		75.7		27	+0.171		1.89
	7/26/65			68.1	92	-0.020		1.70
	9/27/65				62		+0.013	
	3/21-25/66				47		+0.005	
7.								
W. Abut.								
NW	7/2/65	70.0			75			1.75
Fix.	9/23/65		70.5		80	+0.014		1.76
	5/9-13/66			69.7	55	-0.007		1.74
	7/21-29/65				79		-0.003	
	6/24-27/66				90		-0.014	
W. Abut.								
SW	7/2/65	70.0			75			1.75
Fix.	7/12-15/66		72.0		86	+0.051		1.80
	7/21-24/65			70.5	79	+0.014		1.76
	7/12-15/66				80		+0.004	
	6/24-27/66				90		-0.014	
E. Abut.								
NE	7/2/65	72.5			75			1.81
Exp.	1/3-13/66		82.3		40	+0.245		2.06
	8/11-12/66			72.1	86	-0.010		1.80
	7/12-15/66				86		-0.001	
	6/24-27/66				90		-0.014	

TABLE NO. 4.4

BRIDGE AND JT. NOS.	DATE: INSTALL. MAX. & MIN.	DEGREE OF EFFICIENCY @ INSTALL. Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	END MOV. MAX. MIN. PERP.	PARA.	JT. WIDTH "W_j" INSTALL. MAX. MIN.
7. (cont'd)								
E. Abut.								
SE	7/2/65	70.0			75			1.75
Exp.	1/3-13/66		79.1		40	+0.230		1.98
	6/24-27/66			69.3	90	-0.015		1.74
	7/12-15/66				86		-0.000	
	3/28/66-4/1/66				46		-0.017	
11a. skew								
1NW	6/11/65	50.0			82			1.25
Fix.	1/3-21/66		52.9		40	+0.072		1.32
	7/2/66			49.4	85	-0.015		1.24
	7/12-15/66				86		+0.060	
	7/2/66				85		+0.014	
1SW	6/11/65	50.0			82			1.25
Fix.	1/3-21/66		52.5		40	+0.065		1.31
	7/2/65			49.6	86	-0.008		1.24
	--			--	--	--		--
	8/11-12/66				85		-0.080	
2SE	6/11/65	70.0			82			1.75
	1/3-21/66		78.5		40	+0.211		1.96
	6/24-27/66			65.0	92	-0.126		1.62
	7/12-15/66				86		+0.027	
	1/3-21/66				40		-0.014	
2NE	6/11/65	65.0			82			1.62
Exp.	1/3-21/66		75.6		40	+0.271		1.89
	6/24-27/66			60.9	92	-0.100		1.52
	1/3-21/66				40		+0.011	
	6/24-27/66				92		-0.034	

TABLE NO. 4.5

BRIDGE AND JT. NOS.	DATE: INSTALL. MAX. & MIN.	DEGREE OF EFFICIENCY @ INSTALL. Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	END MOV. MAX. MIN. PERP.	PARA.	JT. WIDTH "W_j" INSTALL. MAX. MIN.
17a. skew								
1NE	10/21/65	59.9			66			1.50
Exp.	1/23/66-2/4/66		63.5		25	+0.092		1.59
	8/19-22/66			59.1	86	-0.021		1.48
	1/23/66-2/4/66				25		+0.024	
	4/19-26/66				67		-0.004	
1NW	10/21/65	62.8			66			1.57
Exp.	1/23/66-2/4/66		66.6		25	+0.096		1.67
	8/19-22/66			62.3	86	-0.012		1.55
	1/23/66-2/4/66				25		+0.014	
	4/19-26/66				67		-0.014	
2SE	10/21/65	66.9			66			1.67
Exp.	1/23/66-2/4/66		75.4		25	+0.212		1.89
	6/30/66-7/1/66			57.8	88.5	-0.237		1.44
	6/30/66-7/1/66				88.5		+0.028	
	1/23/66-2/4/66				25		+0.004	
2SW	10/21/65	66.0			66			1.65
Exp.	1/23/66-2/4/66		74.3		25	+0.206		1.86
	6/30/66-7/1/66			56.4	88.5	-0.240		1.41
	1/23/66-2/4/66				25		-0.000	
	6/30/66-7/1/66				88.5		-0.029	
17b. skew								
1NE	11/10/65	72.5			35			1.81
Exp.	1/25/66-2/4/66		74.0		22.5	+0.040		1.85
	8/19-22/66			69.7	85	-0.068		1.74
	1/25/66-2/4/66				22.5		-0.015	
	8/19-22/66				85		-0.083	

TABLE NO. 4.6

BRIDGE AND JT. NOS.	DATE: INSTALL. MAX. & MIN.	DEGREE OF EFFICIENCY @ INSTALL. Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	END MOV. MAX. MIN. PERP.	PARA.	JT. WIDTH "W_j" INSTALL. MAX. MIN.
17b. (cont'd)								
1NW	11/10/65	70.0			35			1.75
Exp.	1/25/66-2/4/66		71.0		22.5	+0.028		1.78
	8/19-22/66			68.1	85	-0.046		1.70
	7/25-26/66				84		+0.034	
	4/18-26/66				66		-0.011	
2SE	11/10/65	77.5			35			1.94
Exp.	1/25/66-2/4/66		81.5		22.5	+0.103		2.04
	6/30/66-7/1/66			63.6	88	-0.345		1.59
	1/25/66-2/4/66				22.5		+0.019	
	6/30/66-7/1/66				88		-0.342	
2SW	11/10/65	75.0			35			1.87
Exp.	1/25/66-2/4/66		79.2		22.5	+0.107		1.98
	6/30/66-7/1/66			59.5	88	-0.386		1.49
	8/19-22/66				85		+0.379	
	1/25/66-2/4/66				22.5		-0.031	
17c. skew								
3NE	10/21/65	72.5			69			1.81
Exp.	1/25/66-2/4/66		81.0		23	+0.214		2.02
	6/30/66-7/1/66			60.9	89	-0.289		1.52
	1/29/65				35		+0.033	
	7/25-26/66				85.5		-0.031	
3NW	10/21/65	67.5			69			1.69
Exp.	1/25/66-2/4/66		75.8		23	+0.208		1.90
	6/30/66-7/1/66			55.4	89	-0.302		1.39
	6/30/66-7/1/66				89		+0.024	
	1/25/66-2/4/66				23		-0.042	

TABLE NO. 4.7

BRIDGE AND JT. NOS.	DATE: INSTALL. MAX. & MIN.	DEGREE OF EFFICIENCY @ INSTALL. Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	END MOV. MAX. MIN. PERP.	PARA.	JT. WIDTH "W" INSTALL. MAX. MIN.
17c. (cont'd)								
4SE	Due to lack of precision these data are omitted from this table.							
4SW	10/21/65	69.0			69			1.73
Exp.	1/25/66-2/4/66		72.9		22	+0.092		1.82
	7/25-26/66			69.2	85.5	-0.002		1.73
	11/1/65				54		-0.008	
	5/25-26/66				76.5		-0.037	
17d.								
3NE	10/21/65	70.0			71			1.75
Exp.	1/25/66-2/4/66		80.4		28	+0.261		2.01
	6/28-29/66			62.1	92	-0.197		1.55
	11/18-29/65				40		-0.063	
	7/20-22/66				84		-0.119	
3NW	10/21/65	70.0			71			1.75
Exp.	1/25/66-2/4/66		79.2		28	+0.229		1.98
	6/28-29/66			60.8	92	-0.229		1.52
	5/24-26/66				77		+0.122	
	7/20-22/66				84		+0.026	
4SE	10/21/65	65.0			71			1.62
Exp.	1/25/66-2/4/66		70.3		28	+0.134		1.75
	6/28-29/66			65.2	92	+0.005		1.63
	11/18-29/66				40		-0.001	
	3/1-3/66				59		-0.020	
4SW	10/21/65	60.0			71			1.50
Exp.	1/25/66-2/4/66		64.3		28	+0.108		1.61
	8/17-18/66			60.0	86	+0.002		1.50
	12/27/65-1/2/66				37		-0.003	
	3/1-3/66				59		-0.012	

TABLE NO. 4.8

BRIDGE AND JT. NOS.	DATE: INSTALL. MAX. & MIN.	DEGREE OF EFFICIENCY @ INSTALL. Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	MAX. MIN. PERP.	MAX. MIN. PARA.	END MOV. INSTALL. MAX. MIN.
17e.								
2NE Exp.	10/21/65	67.5			73			1.69
	1/23/66-2/4/66		74.4		25	+0.175		1.87
	6/28-29/66			61.3	95	-0.156		1.53
	8/17-18/66				86		+0.009	
	10/29/65				44		-0.012	
2NW Exp.	10/21/65	70.0			73			1.75
	1/23/66-2/4/66		76.9		25	+0.174		1.92
	6/28-29/66			63.1	95	-0.170		1.58
	10/29/65				44		+0.019	
	8/17-18/66				86		-0.017	
3SE Exp.	10/21/65	82.5			73			2.06
	1/23/66-2/4/66		90.5		25	+0.203		2.26
	6/28-29/66			77.8	95	-0.117		1.94
	8/17-18/66				86		+0.010	
	10/29/65				44		-0.007	
3SW Exp.	10/21/65	77.5			73			1.94
	1/23/66-2/4/66		85.2		25	+0.193		2.13
	6/28-29/66			72.5	95	-0.124		1.81
	10/29/65				44		+0.008	
	7/20-22/66				83		-0.024	
17f.								
2NW Exp.	9/20/65	62.5			87			1.56
	1/23/66-2/4/66		75.4		25	+0.325		1.88
	6/28-29/66			62.4	91	-0.003		1.56
	8/17-18/66				85		-0.090	
	1/23/66-2/4/66				25		-0.103	

TABLE NO. 4.9

BRIDGE AND JT. NOS.	DATE: INSTALL. MAX. & MIN.	DEGREE OF EFFICIENCY @ INSTALL. Y IN %	@ MIN. TEMP. X MAX. IN %	@ MAX. TEMP. Z MIN. IN %	TEMP. OF AIR °F	END MOV. MAX. MIN. PERP.	PARA.	JT. WIDTH "W" INSTALL. MAX. MIN.
17f. (cont'd)								
2SW	9/20/65	64.1			87			1.60
Exp.	1/23/66-2/4/66		74.9		25	+0.270		1.87
	6/28-29/66			61.9	91	-0.052		1.55
	1/23/66-2/4/66				25		-0.002	
	8/17-18/66				85		-0.017	
3SE	9/20/65	65.0			87			1.62
Exp.	1/23/66-2/4/66		75.4		25	+0.261		1.88
	6/28-29/66			64.4	91	-0.018		1.61
	10/29/65				35		-0.032	
	8/17-18/66				85		-0.069	
3NE	9/20/65	60.0			87			1.50
	1/23/66-2/4/66		68.9		25	+0.226		1.73
	6/28-29/66			57.6	91	-0.060		1.44
	8/17-19/66				85		+0.055	
	4/13-20/66				56		+0.045	

TABLE NO. 4.10

Besides whatever measurements were taken, the regular schedule included visual observations of joints and sealers. In this way, it was possible to collect the other pertinent data listed below.

Starting as far back as November 1965 and continuously through July 1966, our field personnel reports indicated the following GENERAL OBSERVATIONS, common to all or most of the aforementioned bridges.

1. Progressively increasing deterioration of joints. It was definitely established that, besides the spalls already discussed, the spalling and chipping of joints which occurred after the bridges were opened to traffic, were mostly in the traffic lanes on the joint faces opposing the flow of traffic. Photographs #23 to #25 clearly indicate the above pattern which, although photographed only on one group of bridges, is somewhat varied but common to all.

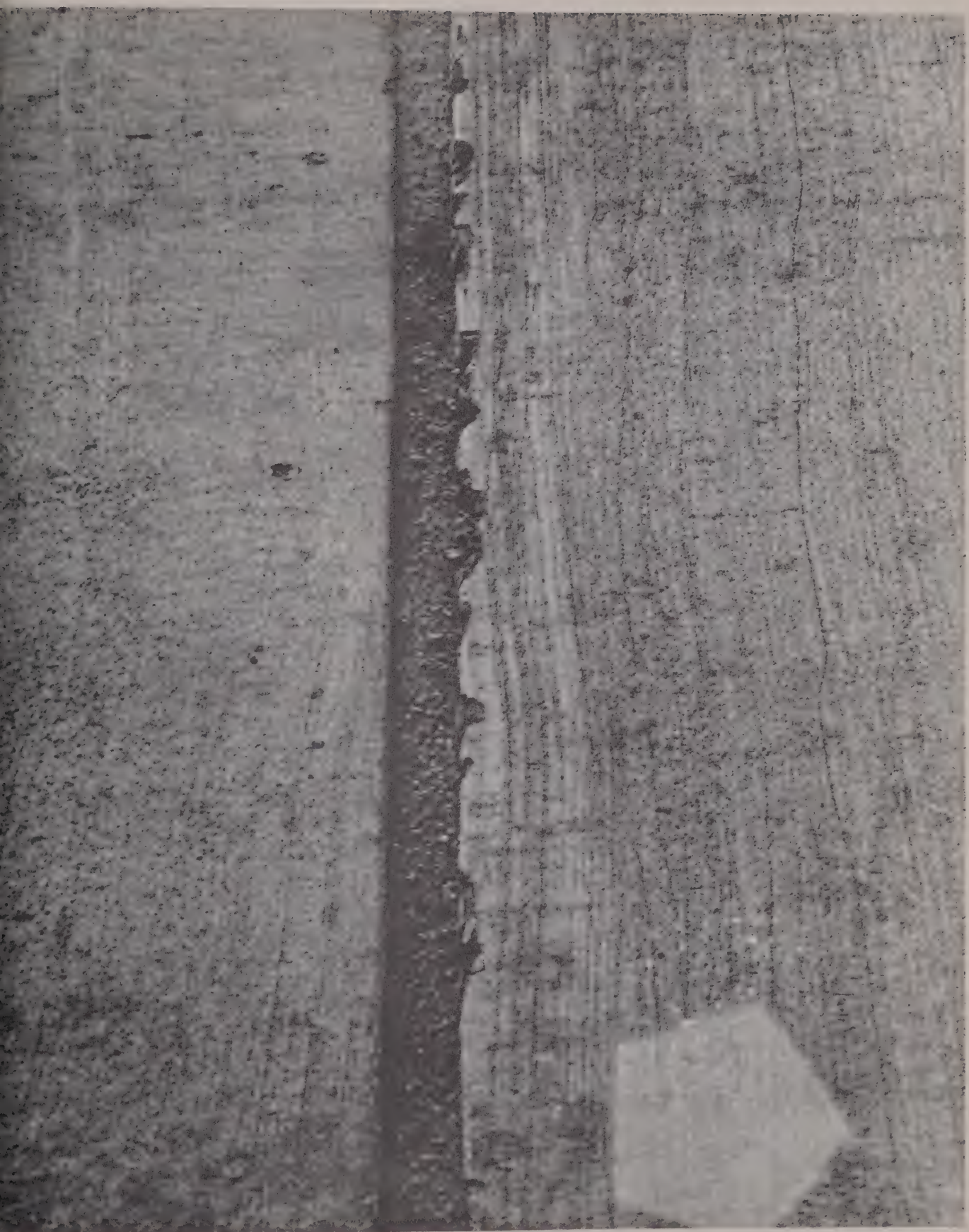


PHOTO NO. 23
Another example of the pattern of spalling
and chipping and accumulation of dirt in the joints.
Bridges No. 17a to f.

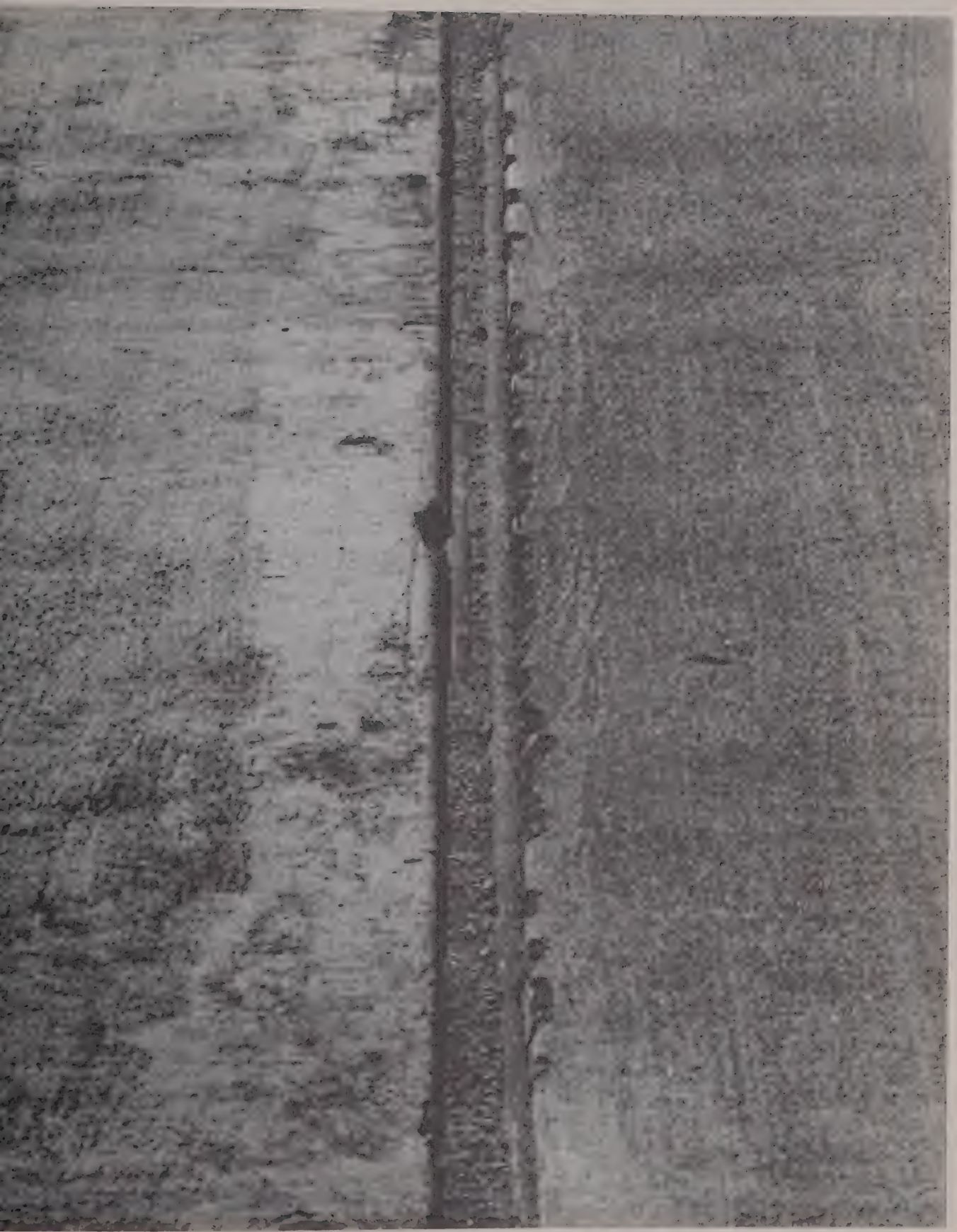


PHOTO NO. 24
Observe the pattern of spalling and chipping and accumulation of dirt in the joints.
Bridges No. 17a to f.

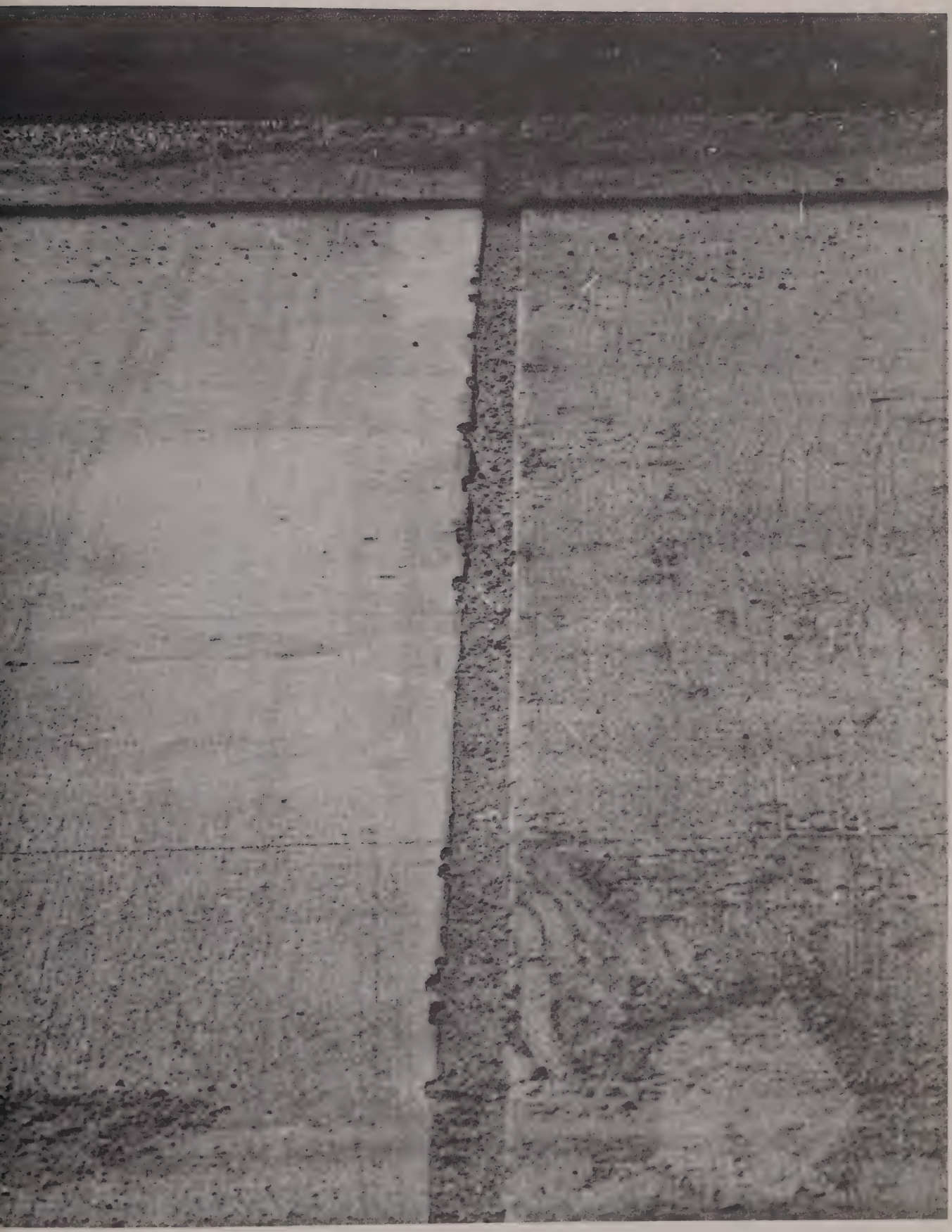


PHOTO NO. 25
Again the spalling and chipping pattern, and the dirt accumulation in the joints.
Bridges No. 17a to f.

2. Sealers, placed into the joints, level with the tops of the decks or above them, are progressively damaged by traffic. They are first scuffed, then cut and torn or forced to migrate vertically. When located at excessive depths, sand, gravel, and too much moisture accumulate in the joints. Photographs Nos. 23 to 26 portray joints with sealers recessed up to one (1) inch.

3. Pools of water at curbs as shown on photograph No. 26 are also fairly usual.

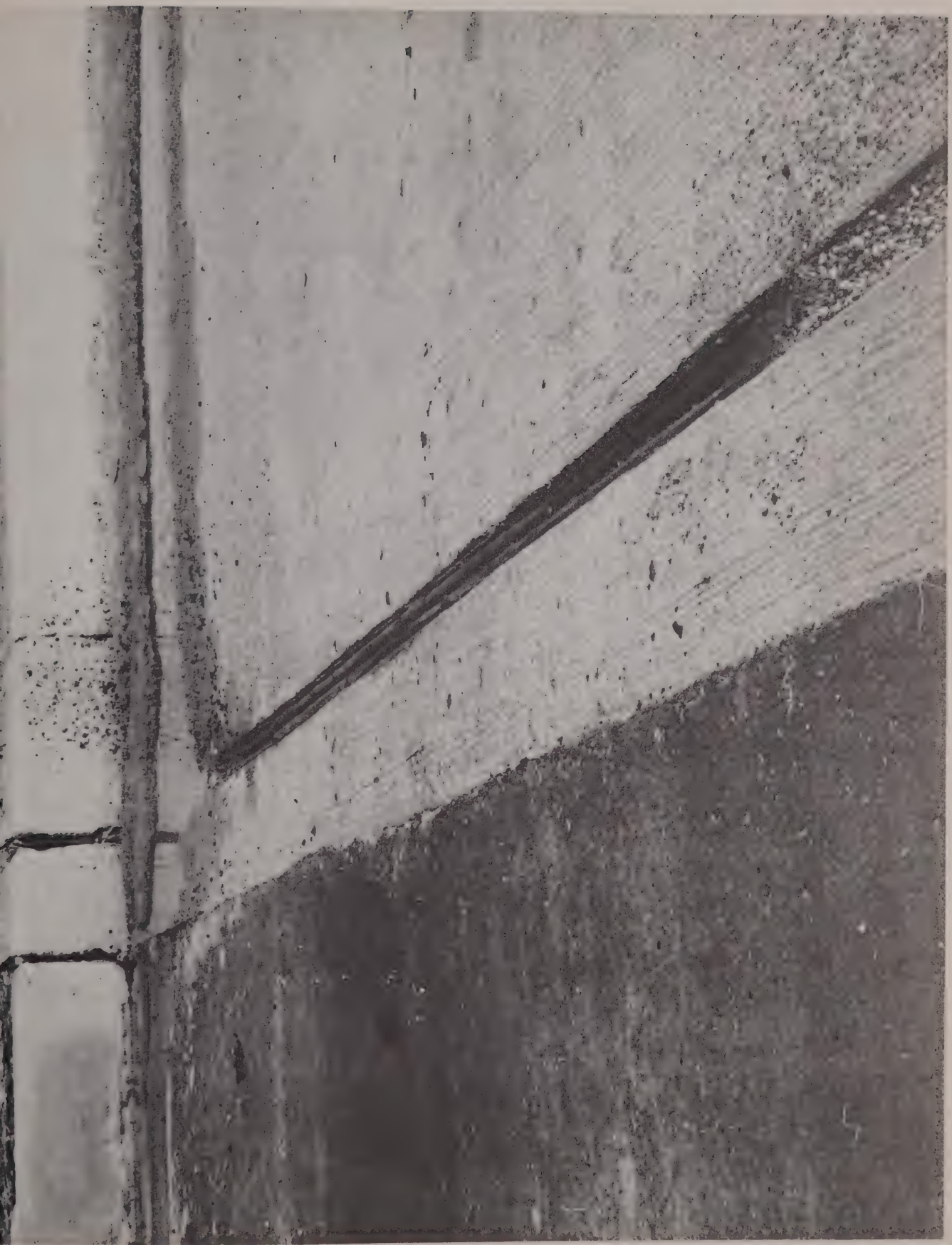


PHOTO NO. 26
Note the depth of the sealers' recess, the dirt and water pool in the joint and at the curb.
Bridges No. 17a to f.

4. Leakage at joints has been observed on many bridges. The causes, as far as could be established, are: joint deterioration, faulty joint sealing details at curbs, and probably, excessively relaxed seals placed into too wide joints. This was evidenced by leakage detected at joint locations where no other visible origins of leakage could be found. Photographs #27 to #35 are illustrations of the above, and are an indication of the seriousness of this situation. Only slow dripping was observed in some cases, yet pools of water, as shown on some of these photographs, were visible. Although photographed on only a few bridges, the leakages in various degrees are quite commonplace. Also salt deposits, visible for instance, on Photographs #28, 29 and 30, were heavy and quite apparent on walls, beams, and near bearings.

PHOTO NO. 27
First of four views showing a pool of water near the bearings, with salt deposits and/or water marks on the walls.
Bridges No. 17a to f.

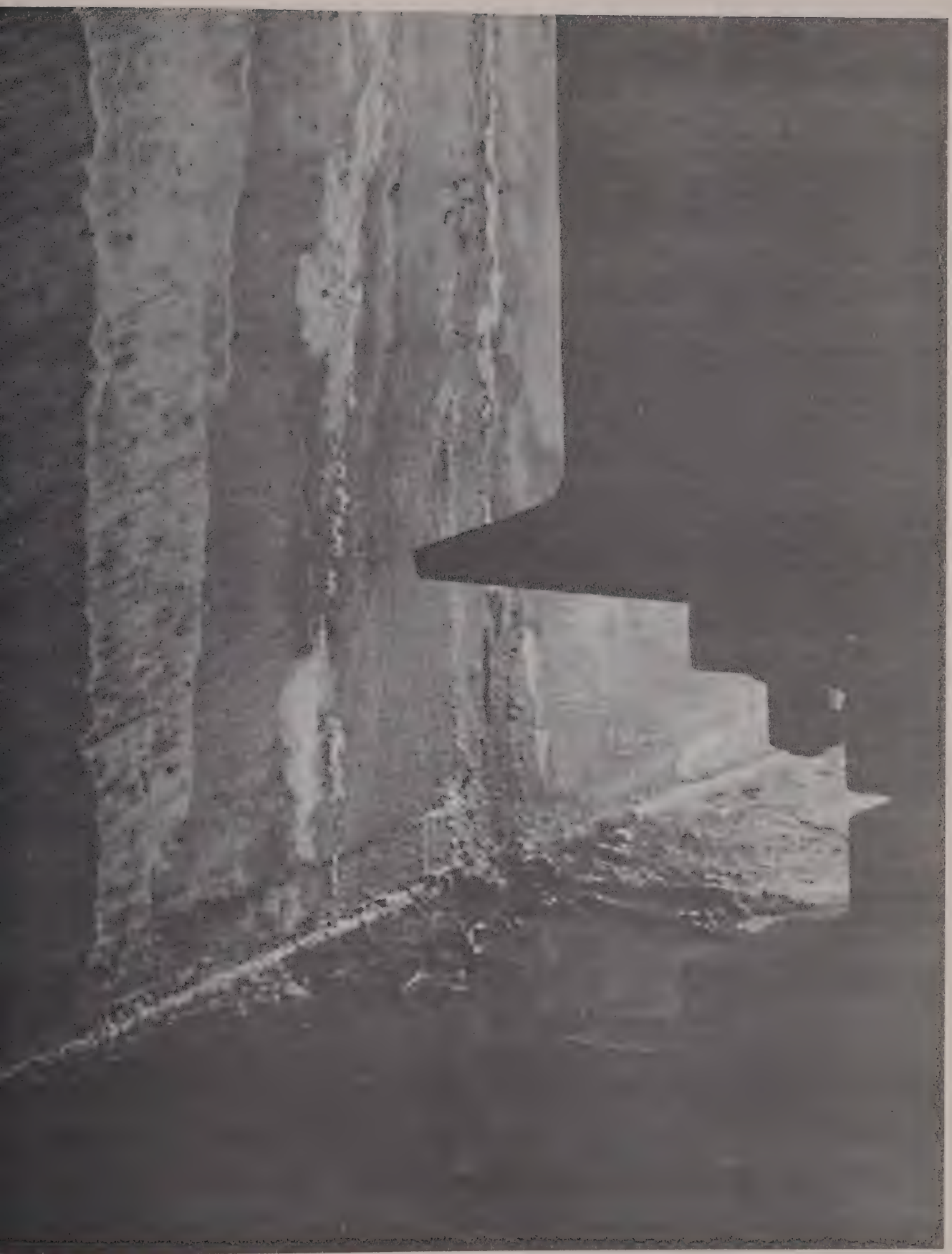


PHOTO NO. 28
Second of four views.
Bridges No. 17a to f.

PHOTO NO. 29
Third of four views.
Bridges No. 17a to f.

PHOTO NO. 30
Fourth of four views.
Bridges No. 17a to f.

PHOTO NO. 31
Example of wet beams and of water
flowing even down the pier.
Bridges No. 17a to f.

PHOTO NO. 32
Observe water marks.
Bridges No. 17a to f.

PHOTO NO. 33
Note the wet beams.
Bridges No. 17a to f.

PHOTO NO. 34
More wet beams.
Bridges No. 17a to f.

PHOTO NO. 35
Wet beams in other locations.
Bridges No. 17a to f.

Tables Nos. 11.1 to 11.7 are attached for further substantiation of the above commentary. Necessarily, less comprehensive data are available on some bridges than on others. It was established however that conditions recorded about the group of six bridges Nos. 17a to 17f, Route 295, Section 1N, were also observed elsewhere on many occasions. It is worthy to note that the joints for these particular bridges were constructed with more care than in most cases seen to date.

Table #11.1

Summary of Periodic Field Observation Data

Bridge No: 15a and c, skewed

Rt. 17, Sec. 5C, Northern New Jersey

1. Condition of Joints: Some spalling is visible.

2. Condition of Sealers: A lengthwise one (1) inch split in the sealer at the top of a curb was detected.

3. Leakage: Beneath the bridge-deck stain-marks are abundant. Wet spot in vicinity of a curb and yellow dye staining at three locations were noticeable.

Table #11.2

Summary of Periodic Field Observation Data

Bridge No: 3a, skewed

Rt. 287, Sec. 11a & 12C, Northern New Jersey

1. Condition of Joints: There is spalling and chipping of joints in increasing amounts.

2. Condition of Sealers: In many locations, sealers which are protruding above the top of the deck, are scuffed, cut or torn. Since sealers are not continuous, there is a progressive opening of gaps between the seal lengths.

3. Leakage: Beneath the bridge deck, especially in curb areas, many stain-marks and wet spots are noticeable.

Table #11.3

Summary of Periodic Field Observation Data

Bridge No: 9b, skewed

Rt. 287, Sec. 6E, North Central New Jersey

1. Condition of Joints: Spalling and chipping of joints is visible in traffic lanes.

2. Condition of Sealers: A vulcanized sealer joint has opened ¼ inch and a split in the sealer at the top of a curb bend was detected.

3. Leakage: Beneath the bridge deck, mainly in curb areas and some in-between, stain-marks were visible. On the deck, mud has infiltrated between faces of joint and sealer at the center of the roadway.

Table #11.4

Summary of Periodic Field Observation Data

Bridge No: 10b

Rt. 287, Sec. 6F and 7B, North-Central New Jersey

1. Condition of Joints: Spalling and chipping of joints is visible in traffic lanes.

2. Condition of Sealers: Some sealers are level with the top of the deck; no damage reported.

3. Leakage: Beneath the bridge deck, in many curb locations and even in an entire joint, there were wet areas after a light rainfall.

Table #11.5

Summary of Periodic Field Observation Data

Bridge No: 7

Rt. 33, Monmouth Co., Coastal New Jersey

1. Condition of Joints: No damage reported.

2. Condition of Sealers: A split, ½ to 1 inch wide across the sealer, is detected on the top of a curb.

3. Leakage: Leakage was noticed at the east abutment's expansion joint in the curb area.

Table #11.6

Summary of Periodic Field Observation Data

Bridge No: 11a

Rt. 35, Keyport, Coastal New Jersey

1. Condition of Joints: Some spalling of a joint at the top of a curb.

2. Condition of Sealers: In some joints, where sealers were reported protruding above the top of the deck, downward vertical migration of them was noticed. Discovered a hole, about 1/8 of an inch in diameter in the sealer bend at the top of curb.

3. Leakage: Some was found beneath the bridge deck in many locations in curb areas and even in an entire joint.

Table #11.7

Summary of Periodic Field Observation Data

Bridges No: 17a to f

Rt. 295, Sec. 1N, Southern New Jersey

1. Condition of Joints: All bridges in this group show the same pattern of deterioration. Spalling and chipping is prevailing in traffic lanes on the joint faces opposing the flow of traffic. Sealers are recessed up to one (1) inch below the top of the bridge deck; this results in excessive amounts of sand, gravel, and moisture accumulation in the joints.

2. Condition of Sealers:

   Bridge #17a: Half (½) inch length-wise split in the sealer below the seal's bend in the southwest curb.

   Bridge #17d: Half (½) inch length-wise split in the sealer at the top of west curb in joint #3. Sealers in the sidewalks at some bridges appear to have sagged, producing pockets capable of holding water. Large spalling leaves sealers relaxed.

3. Drainage: Some water pools were observed on all these bridges.

4. Leakage: Evidence of leakage was noted in various degrees under most bridges in the curb and spalled areas and in some other joint locations. For illustration, see the attached dye test report.

Dye Test

In an attempt to isolate the causes of leakage, a dye test was performed on bridges Nos. 17d and 17e. The conclusions were interesting and quite satisfactory, considering the rather limited extent of the test. It is regrettable that more expanded and thorough tests could not be conducted in order to segregate further the contributory factors of this phenomenon.

The test was conducted on March 4, 1966 in driving rain.

Various colored dyes (yellow, red, blue) were placed at different locations along the joints. Because of weather conditions it was not possible to be selective in putting different colors in adjacent locations. Therefore, no color scheme can be given. Placing of dye solutions started at approximately noon on Bridge No 17e and when finished continued on Bridge No. 17d. At two o'clock the dye was observed leaking from under the joints on Bridge No. 17e; the same phenomenon was established on Bridge No. 17d at about the same time. Approximately half of the dye solution was placed along the curb-deck junction in the joints. The remainder of the solutions was placed in areas of deterioration and in selected large spalls, where the sealers were partially relaxed.

The conclusions are as follows:

Bridge No. 17d - Five positive dye stains were observed. At pier joints the stain could be attributed to a slight deterioration of joints. In the other three cases, at a pier and an abutment joint, the test engineer could not find any set explanation.

Bridge No. 17e - Ten positive dye stains were observed. Five were directly attributable to deterioration, one to a large concrete spall and relaxed sealer, and four occurred along the curb edges. On both bridges other leaks were visible, at locations where no dye was used.

The evaluation of the above test certainly indicates that the deterioration of joints and the gutter areas along curbs, are prime causes of leakage. For the unexplained leakage areas the cause can probably be attributed to insufficient compression of seals.

The record shows that on March 3, 1966 the average efficiency coefficients were: on bridge No. 17e in Jt. #2, 70 to 72%, and in Jt. #3, 81 to 86%; on bridge No. 17d in Jt. #3, 72 to 73%, and in Jt. #4, 67 to 68%. These being average values, the extremes could be easily higher at leakage locations.

Methods of Observation

The regular observation schedule was centered around the measurement of bridge-end movements. While the necessity for instrumentation of bridges for the above purpose was

realized from the very beginning, i.e., as far back as April, 1965, circumstances led to the use of manual methods of measurement.

The drawbacks of the manual method are well known, they reside in the fallibility of human nature, together with the inadequacy of manual equipment and the lack of scientific depth. Examples abound: the assumption of parallelism between the joint and the side S_{11}, S_{12}, ...S_{1n} (see figure 14); the distance 4¼ inch (see figure #13) between the same side and the center line of the joint; the complete absence of knowledge of effective temperatures of concrete (see Thermal Characteristics of Bridge-End Movements) and the actual coefficients of expansion for given bridge decks.

But many of these lacks of precision are of little or no practical consequence. Continuous daily measurements throughout a year would have been desirable but were found impracticable.

This is how we actually worked:

To enable us to follow continuously the bridge-deck-end movements, parallel and perpendicular to a joint, brass plugs were installed across the joints. The plugs were placed at each end of the deck joint, and covered at least one span in each of the bridges under observation. The character of the method utilized permitted to envelope fully only a few bridges. For the locations of the plugs, see tables #9.1 to #9.8. These plugs, with 1/8 of an inch holes in the center, were placed and grouted in holes drilled into the bridge

deck in an equilateral triangle pattern. One side (S1) of the triangle was aligned parallel with the joint and was placed on the expansion side, as shown in figure #13. The distance between plugs was measured by means of an Invar gauge designed for this purpose. See photographs No. 36 and 37.

At the time when the initial plug measurements were taken, the width and the depth of the joints were determined at three locations, as shown in figure #13. Starting at the same date, the ambient air temperatures were measured. Also, the as-built length of the span, affecting the movements of the bridge-deck-ends, and the skew angle of the joints, if any, were surveyed. For this purpose, an Invar tape and a transit were used. With these base data available, a relationship between joint movements and any future changes in the triangle could be established.

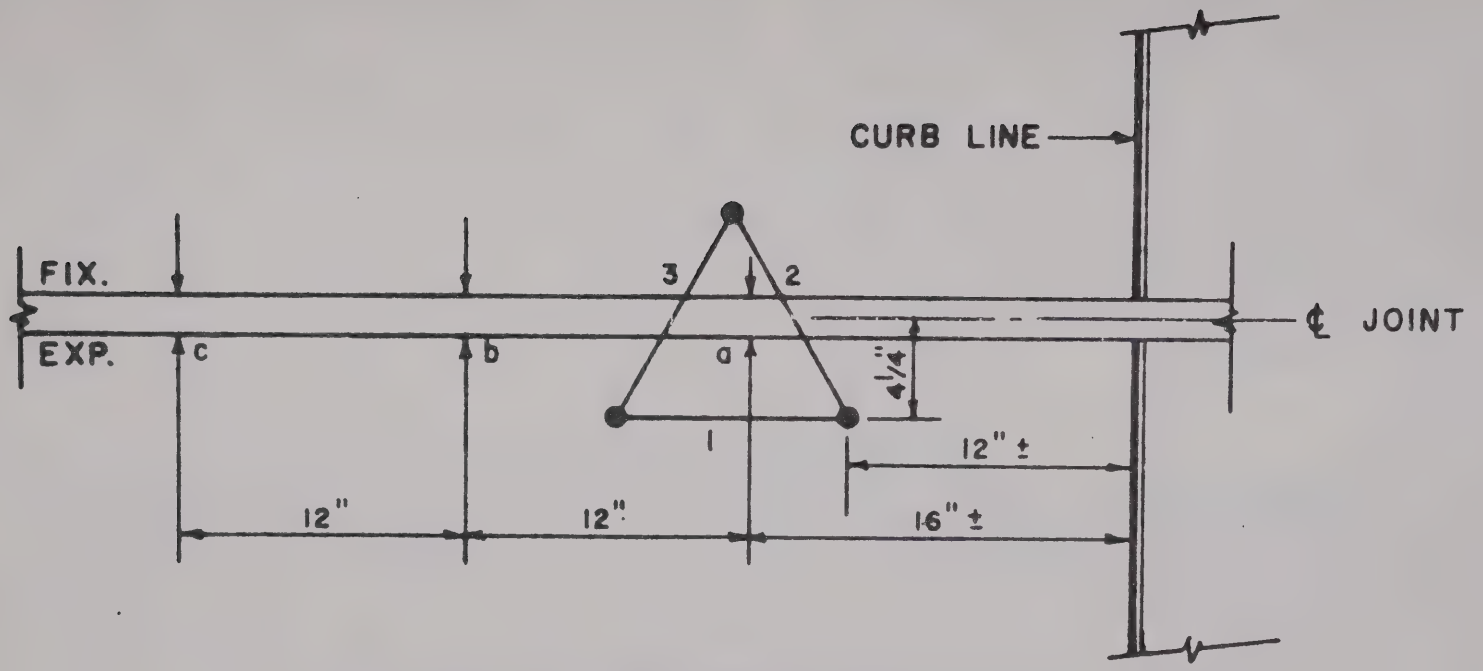


FIGURE #13

TYPICAL PLUG INSTALLATION DETAIL

LEGEND:

The Depth And Width Of Joints Shall Be Measured At "a,b,c" Locations.
The Triangle Sides (S) "1,2,3" Shall Be $9\frac{3}{4}$" ±
Side "S1" Shall Be Parallel To The Joint.
Side "S2" Shall Always Face The Curb.

PHOTO NO. 36
Top view of Invar Gauge. Note the Reference Bar for adjusting the gauge.
The AMES-3822 0.001 "Indicator dial, range 2" is utilized.

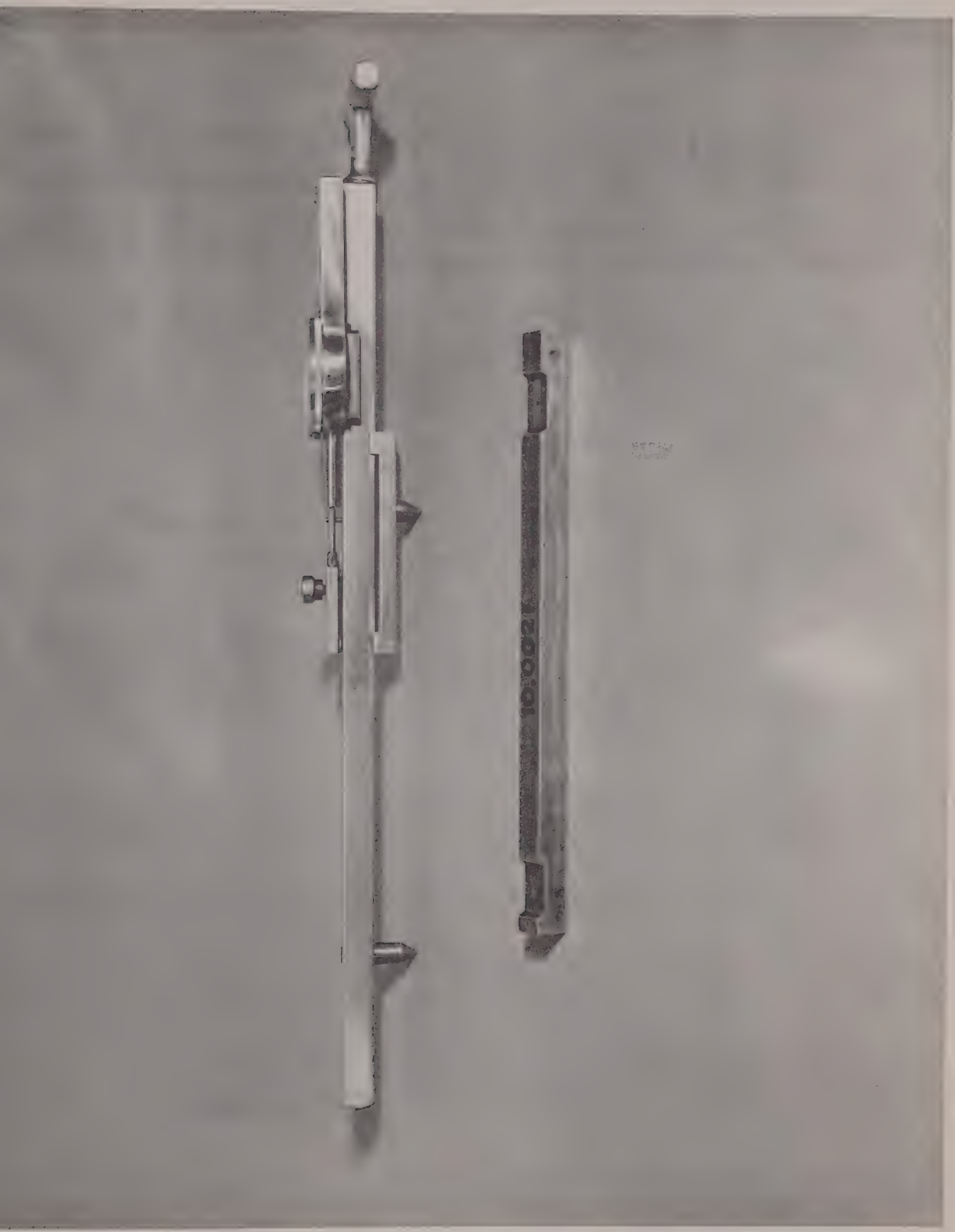


PHOTO NO. 37
Side view of Invar Gauge.

The following methods of calculation were used to convert the plug measurements into joint movements and other pertinent data:

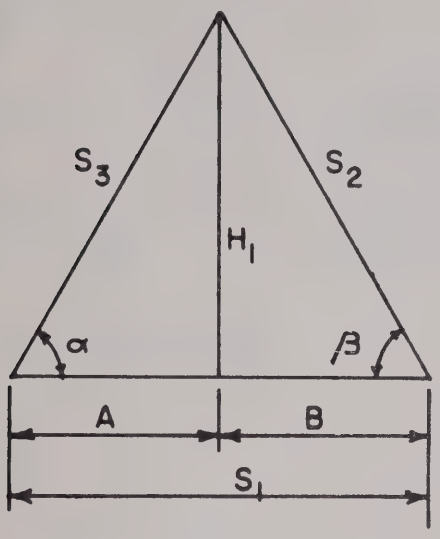


FIGURE #14

$$\cos\alpha = \frac{S_3^2 + S_1^2 - S_2^2}{2\ S_3\ S_1} \quad ;$$

$$\sin\alpha = \sqrt{1 - \cos^2\alpha} \quad ;$$

$$H_1 = S_3 \times \sin\alpha \quad ;$$

$$A = S_3 \cos \quad ;$$

$$B = S_1 - A;$$

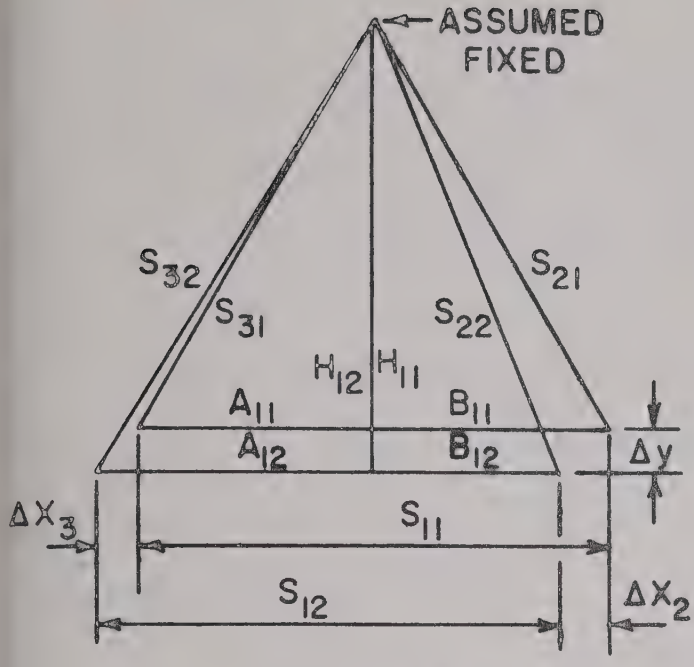


FIGURE #15

ASSUMPTION:
S_{11} is parallel with S_{12}

$$\Delta y = H_{12} - H_{11};$$

$$\Delta X_2 = B_{11} - B_{12};$$

$$\Delta X_3 = A_{12} - A_{11};$$

$$\Delta X = \frac{\Delta X_2 + \Delta X_3}{2} \quad ;$$

$$\Delta X = \frac{(A_{12} - B_{12}) - (A_{11} - B_{11})}{2};$$

Width of Joint: $W_{j2} = W_{j1} + \Delta y$; (in inch)

$$\Delta V = \Delta y \times \cos \rho$$

Length of span: $L_{12} = L_{11} + \Delta V_{12}$; (in feet)

$$\Delta t = \frac{\Delta v}{c\ L} \quad ;$$

Δy - Bridge deck end movement perpendicular to the joint in inch.

ΔX = Bridge deck end movement parallel to the joint in inch.

ΔV = Bridge deck end movement parallel with the supporting beams in inch.

Δt = Concrete temperature increments in ^{o}F

c = average coefficient of expansion.

ρ and ρ^1 are joint-skew angles at the opposite ends of a span.

It is obvious, that the calculations shown are really simple, but in view of the quantity of data, it soon became necessary to facilitate the computational work by a Fortran program, which was written for use on the Department's IBM 1620 computer. Input parameters, employed with the program were: initial joint width, skew angle, span length, and plug readings. As part of the output, the computer provided, by dates, listings of: the parallel and perpendicular joint movements, joint width, efficiency coefficients, change in span length, and concrete temperature increments. For better perception, this information is summarized in the form of graphs, which not only indicate the joint movements, temperatures of air and concrete, and efficiency coefficients, but also the relationship between these elements. For the purpose of this report, graphs No. 1 to 12 for only two (2) bridges are attached. Table #4 is a compendium of the graphs for the thirteen (13) bridges under observation. These data, although only an abstract, are voluminous enough to indicate the quantity of data collected. In order not to cloud the issue, and since this abridgement is sufficiently representative for our purposes, it did not seem necessary to include the complete data in this report.

- -

With this we conclude reporting the factual data collected to date. Before we submit our conclusions and recommendations we shall discuss briefly the desirable ways and means of instrumentation of bridges, since some preparatory work has been already accomplished toward this end.

E/ INSTRUMENTATION

The goals set for the instrumentation of bridges have been defined in our previous discussions. Briefly they aim at obtaining data on effectual temperatures of concrete and of air, and on the movements of the bridge-deck-ends at the joints; all these correlated and continuously recorded for a period of at least one year. We are dealing with a large unit, a bridge deck, exposed to the natural elements, all forms of traffic, and movements of a structure. The guiding purpose remains the sealing of joints.

To establish the effective temperature of the concrete, the deck temperatures should be measured throughout the full depth and over the whole area of a slab. At the same time, a true ambient air temperature should be measured. Since all this has to be correlated with the movements of the deck-slab-ends at the joints, these movements should also be thoroughly measured, perpendicularly and parallel to the joints.

To work within the limits of practicality, it is suggested to install thermocouples at four corners and in the middle of a deck; placing them at various depths, starting near the top and, with each new location, going down at progressively increasing distances to accommodate the non-linear curve of slab-temperature distribution.

The attempt is to obtain as complete a spectrum of temperatures as is possible, while still keeping the quantity of equipment at an absolute minimum. Of course, the measurements taken in the above manner could cause some local deviation from the true temperature curve throughout the depth of the slab. These possible distortions would be the result of the scattering of the thermocouples over the deck area.

To record the ambient air temperatures, only two (2) thermocouples should be placed at proper locations, possibly underneath the bridge.

The measuring of movements, in the given situation, is unique. After some searching, we suggest to adopt the Bourus Linear Motion Potentiometers, or Linear Motion Transducers Sostman Series 1120, with accessories as the most suitable equipment available. Two (2) of these devices must be placed at each of the four (4) corners of a deck at the joints; one to record perpendicular, the other parallel movements at the joints. In this way, four (4) potentiometers per joint are needed, again an absolutely necessary minimum as already substantiated in this report. The multi-channel recorders, such as General Electric Type HG or Bristol's multiprinting recorders, seem to lend themselves to the purpose of continuous recording. The procedure that would suit the minimum needs is suggested as follows:

1. To begin with, for five (5) 24-hourly periods, all measurements would be recorded on an hourly basis.

2. After that, for a period of at least one (1), preferably two (2) years, it should be sufficient to register the same type of measurements four (4) times in 24 hours. The times at which these data are to be recorded should be established from the previous hourly registers. The hourly recordings should also shed some light on the flow of the temperature in the concrete bridge-deck-slabs, as discussed in the study of thermal characteristics of bridge-end movements. Thus, as a by-product, it may be possible to obtain some basis for the further development of formulas for computation of temperatures between the slab surfaces. It is hoped that this instrumentation will provide the true correlation between the temperatures of concrete and of air, and between these temperatures and the deck-end movements at the joints.

F/ CONCLUSIONS

This report contains three basic elements: materials, their applications, and the observation of both.

The testing of the essential product, the sealer, in our own laboratories needs further development. Such testing is absolutely essential to the knowledge of the material.

Nevertheless, in the overall picture, the knowledge we accumulated allows us to make with certainty these two major statements:

1. The method of design and especially of construction, as presently applied, are defeating the functional usefulness of this type of sealer, regardless of its quality.

2. The basic requirement for the sealer to be functional, namely to be compressed within the efficiency limits of 40% to 80% of its original width, appears to be defeated by the manufacturing methods. More specifically, the physical dimensions of the sealer, as supplied, do not permit it to be safely compressed to 40% of its original width, or its "minimum compressed width", without compressing the solids.

The basic material of which this product is manufactured appears to be quite adequate. In this report we furnish the material specifications. But, as already stated, present-day testing is not yet adequate. As a result, all existing specifications of the finished product, for all practical

purposes, do not tally with the reality of sealer applications. The answer to that must be more advanced and sophisticated research. The instrumentation, as proposed by us, is only one step in this direction.

This report has shown the ways to remedy the design and construction methods and indicated the inadequacies in the manufacture of sealers. To find ways for improving the production methods is a job for industry.

It is clear, that these improvements are essential for the success or failure of the application of preformed elastomeric joint sealers in the construction of bridges.

Unavoidably, such improvements will increase the initial costs, but such costs are well warranted, as we have shown. The price of the present deficient product is really too high.

With the suggested improvements, and considering the decrease of long range maintenance expenditures and thereafter safety of structures, we can look forward to lower overall costs - all this is true only if a reasonably successful application of this type of sealer is perfected.

Our intention in undertaking this project has been to expose the complexity of bridge joint sealing, and to open new avenues of research.

Problems such as thermal effects and applications of polymer materials in the field of construction are here to stay and will remain subjects for research of considerable value and magnitude.

G/ RECOMMENDATIONS

In this report we have offered a number of solutions to the problems encountered. It must be understood that the proposed methods are essentially an attempt to improve the design of joints and to minimize or eliminate the possibility of inadequate joint construction regardless of the observed causes. It is obvious that it remains to be seen whether the suggested new methods of design and construction will furnish the required results.

For greater clarity our suggestions are reviewed hereafter.

1. The tentative specifications for the supply of elastomeric joint sealers, are suggested for use until better ways to define an adequate product are developed.

2. We suggest not to accept any sealer before it has been thoroughly tested in the users' own laboratory and in accordance with the proposed specifications.

3. The production of sealers should be improved until their dimensions and all other characteristics are of uniformly good quality. Improvements are necessary if sealers are to be functional at all times within the suggested limits. This job, as said before, is the responsibility of the manufacturing industry.

4. The design methods, particularly for the sizing of sealers and joints, are also offered as interim solutions until more precise procedures are evolved. Charts Nos. 1 and 2 and Tables Nos. 2 and 3 are available to serve as guidelines.

5. On the design concept for the construction of joints we strongly suggest the armored joint construction method as analyzed and illustrated in Figure 11 in the report. It is felt that this method is the most suitable for use with the subject sealers.

To support the improvement program we have outlined, the development of an advanced research program is necessary. We make the following recommendations:

1. At least two experimental bridges should be designed and constructed in accordance with the concepts outlined in this report and under the auspices of research personnel. Each bridge should contain armored and sawed joints.

2. The observation of these bridges should include visual observations, dye testing, and other tests and experiments, as found necessary, with particular emphasis on adequate instrumentation.

3. A testing program should be undertaken for the sole purpose of developing realistic material specifications closely related to the actual field applications of the products. The direction which such a program should take has already been indicated by the work done by the industry

and the States of New York and Pennsylvania, as briefly discussed in the text.

4. Such a program should include the thorough testing of all sealers removed from joints for reasons of failure or otherwise.

5. The results of the acceptance testing of sealers should also be a part of this program.

6. Until this new program is developed, the present methods of field observations and manual measurements should continue, and should be strengthened as soon as possible by the instrumentation discussed in the report.

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